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VISITS TO EUROPEAN NAVY YARDS AND SHIPYARDS DURING THE SUMMER OF 1906

By CECIL H. PEABODY

THE policy of all leading maritime nations is to build the major part of their warships in their private shipyards and to equip and repair ships in the governmental navy yards; at the same time all important navy yards have provision for building ships, and some construction is usually in progress. This policy encourages private enterprise and develops the capacity for shipbuilding, both governmental and private, so that all resources may be available in time of need. The first impression that a visitor gets of an important navy yard is consequently made by the provision for equipping and repairing ships, consisting of tidal or closed basins, dry docks, and cranes or derricks, together with a vast assemblage of shops and storehouses for making and storing the numberless things that are required for equipping a warship. As governments are apt to be even more conservative than private firms, it is likely that the buildings and appliances will be found to be old and sometimes inconvenient, or old and new may be found in incongruous juxtaposition. These considerations, together with incommunicativeness of European governmental officials, will explain why there is less to report from navy yards than from private yards; though of private yards it may be said that some were generous in giving information and others were reserved, depending on personal inclination.

Six navy yards in all were visited and thirteen private yards. One navy yard was selected in England, in France, and in Germany, and three were visited in Italy, the arrangement being determined in part by the limitations that appeared proper in arranging an extended trip covering a considerable territory and with other objects in view of at least equal importance, and in part by the fact that important English and French navy yards had been previously visited. Two of the Italian yards were of special interest, one for an experimental model station and the other for the importance of its new construction.

Portsmouth is the principal naval station of Great Britain, and is also the location of the largest and most important dockyard. Some idea of its extent can be learned from the fact that there are eighteen dry docks, not counting certain passages from the tidal basin to closed basins which can be used as docks if necessary. A large amount of the work of equipment and repair of ships is done while lying alongside of wharfs in closed basins, this giving advantages from the fact that the water level remains fixed and the ships do not rise and fall with the tide. The entrance to such closed basins is through locks with gates at each end, and depends on the stage of the tide in so far as that controls the convenient entrance to a lock from the tidal basin. The number of slips available for building has been reduced recently to provide for the increasing demands for equipment and repair; this is in conformity with the policy of giving the major part of new construction to private yards. At the same time the slips retained have been lengthened as demanded by the increase of size of warships. On one of the slips was built the *Dreadnought,* which is remarkable for its speed and power and for its rapidity of construction. The keel was laid in October of 1905, and the ship was launched in February, four months later; now the ship has been placed in commission, and has passed through the power and speed and gunnery trials within a year from the date of launching. This ship was seen in dock, but information was given that even British naval officers could not go aboard without special permission.

Alongside of the slip where this ship was built was a ship tool house, into which material was brought by rail as required. After being machined, this material was passed through the open side of the shop to the slip and hoisted into place by wooden derricks. This method of using a row of wooden derricks on each side of the building slip is common in Great Britain and has some advantages, especially when hoisting is done by electric winches.

A large, new machine shop has just been completed with most modern machinery and appliances on land that has recently been added to the yard.

The principal Mediterranean naval station belonging to France is at Toulon, and there is found one of her oldest and most important navy yards. There was no building going on at this yard when visited, excepting submarine boats, and they were at a detached yard across the harbor and were entirely closed to visitors. As there is practically no tide in the Mediterranean Sea, there is no occasion for closed basins. There were formerly in this yard a number of imposing ship houses built of stone in the classic style, but they have been destroyed by fire, and only the scorched side walls remain. The location of the slips has been largely converted to the purposes of equipment, as that feature has been more emphasized. The half ruinous and temporary appearance of much in this yard had an unfortunate effect, and led to the consideration of the economics forced on the navy by the enormous burden of the French military establishment.

The undeveloped condition of shipbuilding in Italy, except at one or two private yards, has led to the construction of an unusually large part of the warship at the navy yards. Of these the yard at Castellamare appears to be in the best condition for building. This yard is near Naples, and for administrative purposes is considered to be a part of the arsenal, or navy yard, at Naples, which latter is old, small, and poorly arranged, and is used only for small repairs and for fitting out the ships that are built at Castellamare. The yard at Castellamare appears to be rather contracted, and the arrangements of new construction appear to be unduly affected by that condition; otherwise the yard is, or will soon be, in first-class condition for building a small number of ships. There are two masonry slips of solid construction; on one of these *St. George* is building, and arrangements were under way at the time of my visit to build a very powerful ship with steam turbines. A large, new shop for ship tools, with a "saw-tooth" roof, has just been completed, and is partly supplied with powerful modern tools; some are English tools and some are of local design. The equipment of this shop was in progress, and when completed will give every facility in that direction. There are a number of old shops, with small tools and forges for making ship fittings.

The materials for shipbuilding are brought to the yard by rail, but inside the yard are transported entirely on two-wheeled handcarts and hoisted by derricks at the slips.

In this yard there is a complete plant of English machinery for making rope, with breaking, combing, drawing, and ring-spinning machinery. The material is hemp raised on the campania, and is considered superior to manila hemp.

Another Italian yard at which building is in progress is at Spezia, which is the principal naval station. This yard, which is very large and in general very well arranged, is employed mainly on equipment and repairs, and the new construction is said to be subject to delay on account of the pressure for repairs. There are two slips for large ships and two for smaller ships. The bending slab and a shipsmith shop are alongside the outermost slip; the other shops for ship tools, etc., are placed across the inner ends of the slips, so that they are convenient for all of them. Material is transported in the yard by handcarts only, but is hoisted up to the slips by electric winches, the derricks being constructed from discarded military masts taken from naval vessels. Over the ship was spread a canvas awning, to protect it and the workmen from the sun, which at the end of May was already very oppressive in the yard. It may be noted, in passing, that Spezia has the reputation of being favorably located, so that the temperature is moderated by sea breezes. The ships built at Spezia and also those built at Castellamare are supplied with engines built by private firms, such as Guppy or Patterson, at Naples, or Ansaldo-Armstrong, at Sestri Ponenti.

The navy yard at Venice is old and small, but is now in process of reconstruction; and when remodeled will be an effective yard for its size, and will be important on account of its location, though it is probable that it cannot be readily enlarged on account of local conditions. The only important work in progress, aside from the reconstruction of the yard, is the building of submarine boats, which, as usual, was going on in closed shops not accessible to strangers.

The last navy yard to be visited was at Kiel, the principal German naval station; and, as was to be expected, this proved to be a large, well-arranged yard with the most modern appliances. It has recently been enlarged at the expense of the Germania shipyard, which in consequence has been forced to acquire other land at some disadvantage. There are now four old and comparatively small docks at this yard, and two new docks that can accommodate the largest ships that have been planned.

This yard is, in a manner, the home station for a large number of vessels of all classes, including many torpedo boats. Each vessel that is so related to the yard has a section in a storehouse which is specially

assigned to it. In that section will be found all the spare parts and other material that the ship is likely to require on short notice, ready for immediate delivery. The officer who acted as guide pointed out certain sections belonging to ships in active service which were sparsely occupied by such things as a ship might need promptly, but which could not conveniently be carried aboard; other sections belonging to ships laid up at the yard were nearly full of material that it was considered best to have in such a storehouse, all arranged in systematic order, so as to be open to inspection and immediately available. It may be of interest to call to mind that after the proclamation of the German empire the reorganization of the navy was at first entrusted to a cavalry general, who, however, never had a command at sea. This arrangement of spare parts and supplies is only one of many indications that the German navy is at all times kept in condition for immediate service.

In planning a tour of inspection of private shipyards, it was considered best to select the best examples in the various countries visited, taking account of any special conditions, such as continued experience over a term of years, or recent construction in favorable location, or the specialization on a certain class of work. Some yards that have a wide reputation were omitted, either because they would require an undue extension of a trip already sufficiently extended, or because they had been previously visited, in some cases more than once. The order followed will be that of the itinerary of the trip, which will call attention to the Continental yards that had not been previously seen.

The first private shipyard visited was at La Seyne, across the bay from Toulon, an old established yard that has apparently developed in an individual manner, and consequently presented many points of interest. The yard has plenty of room, and has especially a long water front without being unduly limited in width. About the middle of the length of the yard is a large, wet basin for finishing and fitting out ships after they are launched. In front of this basin are the administration offices and drawing offices, which are the centre of administration and supervision. To the left of the basin are three slips for small ships, and at the right are three slips for large work, all with masonry foundations. These at once give a measure of the importance of the yard. To the left and right beyond the slips are shops that come down to the water front, so that work may be taken from them on floating cranes when that method of transportation is convenient. There are also two marine railways, one at the left for small craft, and one at the right for large ships.

In much the same manner as the slips and shops along the water front are related to the wet basin at the middle, the shops for the various industries required for building a ship are distributed along the landward boundary wall to the right and left of the offices. To the left are a series of shops, in one continuous building, for making rivets, for copper work, and for electric fittings. To the right, and therefore across the front of the large building slips, are two ship tool shops, with bending, flanging, and planing machines, including an armor-planing machine. In these shops are shears, punches, and drilling machines, but in addition shearing and punching machines are scattered through the yard, especially between the slips, without any protection from the weather. This arrangement is found more or less all over the Continent, even in Germany, and to some extent in Great Britain. It is to be remembered that in none of these regions where shipbuilding is found do they have the semi-arctic winter of the North Atlantic seaboard. The use of electric transmission of power lends itself to such a scattering of tools, and is increasingly used both at La Seyne and in other yards where the tools are found between the slips. The carpenter shop and mold loft are found to the right of the large ship tool shop. One feature worthy of note is the large size of plating models, some of which are 20 feet long.

All material comes to the yard on wagons drawn by horses, entering at the extreme left and with an open avenue running the length of the yard. There is no other means of transportation than by horses or by men, except as heavy materials and structures are moved by floating cranes, of which there are four in all, one lifting 80 tons, one 50 tons, and two 20 tons each. This extensive use of floating cranes is one of the advantages of the tideless sea on which the yard is located, for as there are no appreciable changes of sea level there are no tidal currents, and as the water front is well protected from the open sea cranes with their loads are easily moved from place to place. The material when brought to the building slips is hoisted by electric winches. A feature of this yard, which showed many evidences of age, was the large and increasing use of electric transmission of power. The material for shipbuilding was stored at the two ends of the yard beyond or in front of the shops at the water front, the principal store being near the entrance, where there was a traveling crane to assist in unloading and loading plates onto wagons and handcarts, but it was worked by hand.

There are two features in this yard that are worthy of special mention, namely, wet ends for building slips and the large marine railway. The

marine railway is notable in consequence of its size and power, and in that it appears to be used instead of a dry dock. The ship to be hauled up is placed on a cradle on sliding ways lubricated as for launching. At the inshore end of the sliding ways is a heavy crossbar, to which are attached two hauling rods about 8 inches in diameter. The motive power is furnished by two hydraulic rams about 15¾ inches in diameter, with a stroke of about 13 feet; and as the hauling rods are made in sections having the same length, the ship may be hauled up intermittently 13 feet at a time, the rams being run back while a section of the hauling rods is being removed. The cradle, when not in use, is drawn up on the railway by electric winches.

Wet ends for building slips are found in shipyards both on the Mediterranean and the Baltic Seas, both being free from tides. The device has certainly been long in use at La Seyne, if it did not originate there. It appears to be employed to give the same advantage at launching that is had on the open sea by choosing an extra high tide for launching, at which time the water extends a considerable distance up the slip. To prepare a wet end, the earth is excavated to the slope of the building ways, side walls of masonry are built, and a gate is provided to exclude the water. The water is pumped out as from a small dry dock, and sluices are provided to flood the space when desired. The gate can be lifted by a floating crane, and thus be put in place or removed when required. Small craft can be docked or repaired in such a wet end when the slip is not otherwise occupied.

The most important Italian shipyard belonging to the Ansaldo-Armstrong Company is located at Sestri Ponenti, near Genoa. It is noted for its construction of ships of large size and power for the Italian and other navies. The *Christobal Colon* was built at this yard and purchased by the Spanish government, just before the difficulties that led to the battle at Santiago. This shipyard is compact and well arranged, with slips for building five or six ships. At the time of my visit there was no work in hand except a number of torpedo boat destroyers on temporary blocking. There were excellent ship tool and forge shops in a central location, with powerful modern tools. Here, as at La Seyne, shears and punches were set in the open between the slips. A branch from the railroad enters the yard at one end and passes under some of the building slips. One of the slips is to be lengthened over the main line of the railway which skirts the inshore side of the yard. The slips, which are built of masonry, stop 40 or 50 feet short of the water edge, which is

the open sea at the Gulf of Genoa. The ships are launched over the beach on a fore-slip that is kept in readiness and is put in place rapidly just before the day chosen for launching, because the beach shifts quickly and to a considerable extent. Material is transported on handcarts within the yard, and is hoisted by hydraulic lifts between the slips. Electric winches are to be substituted for these lifts.

A remarkable sociological question was raised by the superintendent, who said that the trades unions desired to have the working day limited to eight hours, while the workmen, who were paid by the hour, insisted on working twelve hours, which he thought was undesirable from the company's point of view, as men cannot work effectively such long hours.

The Vulcan shipyard, at Stettin, is an old establishment that has taken a leading position in the modern development of the German shipbuilding. It has grown with the growth of shipbuilding until it has outgrown its location, and the yard is consequently cramped and subject to some inconvenience of arrangement. At the time of my visit a plan was in hand for a new shipyard, with a logical arrangement and the most modern appliances, at Hamburg, but it was not then accepted. The establishment is divided by a public street, the shipyard proper being on the water front, and the foundry, machine shop, boiler shop, etc., being on the opposite side of the street. This latter part of the establishment included a locomotive shop, and is capable of doing work in excess of the requirements of the shipyard.

The yard will be described first by aid of the accompanying plan (Fig. 1). It has four slips for large ships, all under ship houses with traveling cranes. Each slip has two cranes, one somewhat longer than half the breadth of the slip, so that its trolley can deliver material directly on the keel; the other crane is of course shorter, and serves the other side of the slip. There are three shorter slips that are not under ship houses. All these slips have wet ends like those seen at La Seyne, the condition of the yard on a tideless sea being quite similar. Some of the wet ends were in use as dry docks for repairing small craft. This yard further resembled the Mediterranean yards in that shears and punches were distributed around the yard near the slips, but they were in general covered with small galvanized iron shelters. This distribution of tools and the large number of small sheds and the haphazard extension of shops to suit the growth of work give to the whole establishment an appearance of lack of system which a more careful consideration shows to be mainly superficial. Thus the plate storage is placed beyond the

slips near the water front, in consequence of the narrowness of the yard, and the joiner shop, sawmill, and timber store are beyond the plate storage, which arrangement was made deliberately, so that a fire in the

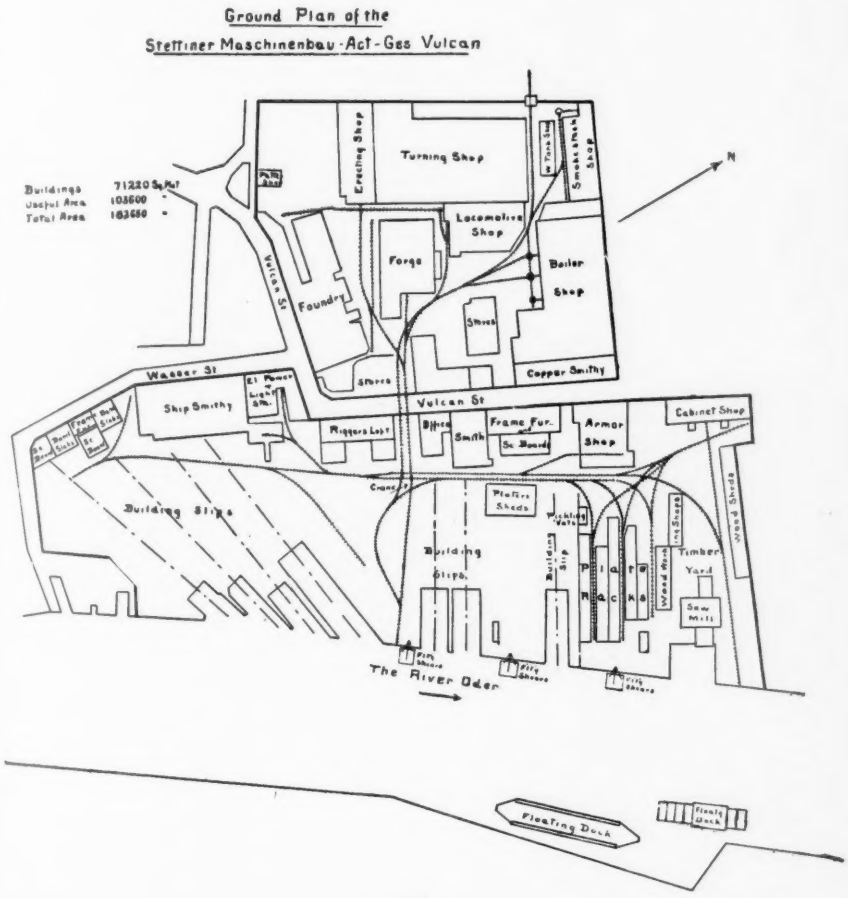


FIG. 1

wood shops would not be communicated to the building slips. The entrance to the yard from the street is at the middle of the length. To the left on entering, the row of buildings on the street are an office, a shipsmith shop, a heating furnace, and two bending slabs and accompanying scrive boards, and then an armor plate shop; beyond, in the

corner of the yard, is the cabinetmaker's shop. To the right is first an assemblage of small buildings, then a shipsmith shop with galvanizing tanks, and in the right-hand corner of the yard another heating furnace, with two bending slabs and scrive boards, which serve the larger building slips. In this corner of the yard the crowding is most evident. Throughout the yard is a very complete system of standard gauge rails that extends into the shops and foundry on the opposite side of the street, and which connects with the railway system. The equipment of the yard includes two floating docks (one capable of taking large ships), which lie on the further side of the Oder, and which must be moved to allow for launching large ships. There are also two catamaran floating cranes, one capable of lifting 150 tons, and the other 120 tons. The location of this yard on a tideless sea lends itself to the convenient use of floating cranes.

The depth in front of the launching slips has been dredged to 33 feet and the depth in the channel to the open sea is maintained at 24½ feet, and yet the company, as already said, has decided to establish a yard at Hamburg, where there is not such a restriction on draft.

The enclosure containing the machine shops, boiler shops, etc., on the further side of the street, has less than half the frontage of the shipyard, but has sufficient depth to compensate, and the shops, though closely assembled, do not give the same impression of crowding. At the entrance are the office building and a general storehouse. Taking a circuit of this yard towards the left, there is formed first a long building with traveling cranes, which is the iron and steel foundry; only small steel castings are made, but there is every appliance for making the large and intricate iron castings demanded by modern marine engines. On the floor of this shop, at the time of my visit, there were a number of molds for cylinders and other large castings in various stages of completion, offering an interesting exposition of this most difficult part of the molder's art. To the right of this shop, as seen on the plan, is the blacksmith shop, with power hammers of moderate power; all large forgings are made elsewhere. Beyond the smithy is a large machine shop, with its equipment of heavy machine tools and erecting floor. Adjacent to the shop for building marine engines is a shop where locomotives are built. At the right of the enclosure is a group of buildings, which are the boiler shop (for both marine and locomotive boilers), the coppersmith's shop, and a shop for building smokestacks and uptakes. As already mentioned, the yard system of rails is brought to or into all of these

shops, and it connects with the railway system at the northwest corner of the enclosure.

One peculiarity in the machine shop was a double-decked arrangement of traveling cranes, one set on a track above that for the other, so that either crane could traverse the whole length of the shop (when unloaded) without interfering with the other, and thus each could be made to serve any part of the shop, and both could carry loads at the same time nearly the entire length. A few minor details were noticed in the machine shop; for example, the eccentric strap, instead of having a straight cylindrical bearing surface on the eccentric, with lips to maintain alignment, had a double wedge-shaped bearing that dispensed with lips, as shown by the sketch (Fig. 2).

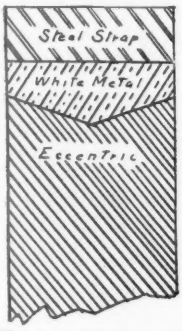


FIG. 2. — SECTION OF ECCENTRIC STRAP

Some double-ended marine boilers under construction had common combustion chambers for opposite furnaces, an arrangement which reduces the length and weight of the boiler, but which has been found to lead to troubles in service. Consequently it would appear that German engineers have not found such troubles insurmountable. A very ingenious swaged joint was seen for the corners of the shell plates of marine boilers, which is too technical for description in this report.

The management of this establishment was most liberal in giving information and every facility for seeing the yard and work in progress, and even showed a proposed plan for the new establishment at Hamburg.

The largest and most recent German shipyard is the Germanic Werft, at Kiel, which was laid out *de novo* in 1896 by Krupp, in connection with his extensive steel enterprises. It adjoins the navy yard at Kiel, and the government has taken land on the water front that formerly belonged to this yard, and that may account for the relatively narrow water front of the yard as now laid out. It is, however, possible that the width of the yard may be extended on the side remote from the navy yard, if that should appear necessary. As the land rises back from the water front, the foundry and boiler shop, as well as the pattern shop and the electric station, are on land that has been excavated to a considerable extent, and which shows high retaining walls on three sides. As the yard is now arranged, there is but little allowance for future growth. This may not be of importance, as the original plan is on a

very large scale, and the works are probably as large as can be run advantageously under a single management. The plan of the yard which accompanies this description (Fig. 3) shows that it is compactly and conveniently arranged to carry on a very large business. At the time of my visit there was relatively a small amount of work in hand, which condition always presents an unfortunate appearance. The construction of building slips, ship houses, machine shops, etc., is substantial, and they are equipped with the most recent machinery and means of handling material, such as fixed and traveling cranes. It is, however, a little remarkable that electric transmission of power is not carried to a further extent; for example, all the tools in the machine shop are driven by belts. In general, the impression is that the design of the yard is conservative, not to say commonplace. On the other hand, the administration offices are in a pretentious building in the Old German style of architecture.

The water front of the yard faces to the north and west, there being an obtuse angle of about 150° at about two-fifths of the length from the northern end. The building slips lie to the north of this bend, and face nearly due north. There is space for ten slips, of which seven are now completed, which vary in length progressively from 450 to 750 feet; the three projected slips are much longer, running up to a possible length of 1,000 feet. The first four shorter slips are covered with lofty ship houses with glass roofs, supported by the framework which carries the traveling cranes. These cranes, which convey material to the ships and support it in place during construction when that is advisable, are in pairs, each slip having two, one on each side of the keel blocks; heavy weights or material to be delivered directly over the keel can be carried by the pair acting in unison. Across the inner end of the slips is the ship tool house, and at right angles with this shop, under a continuous roof, are a series of shops, such as the ship's forge shop and the frame bending shop. The plate storage is in the angle between the shop just mentioned, and being triangular in form is conveniently served by a radial crane; one end of the frame of this crane rests on a pivot, and the other rolls on a circular arc. At a corner of the plate storage is the pickling tank, to remove mill scale from plates.

On the longer side of the water front, which runs a little east of north, is a continuous fitting wharf, served by four cranes with the capacities of 30 to 150 tons. Near the southern end is the machine shop for building and erecting engines. Adjacent to it and between it and

the ship tool house is an assemblage of small shops, such as the coppersmiths' shop, the joiner shop, and the locksmith shop. In this same space is a shop with several slips for building torpedo boats.

The machine shop is all one story high, arranged in four bays, of which one, where the engines are erected, has a greater height than the others. In front of the erecting bay is the 150-ton crane already men-

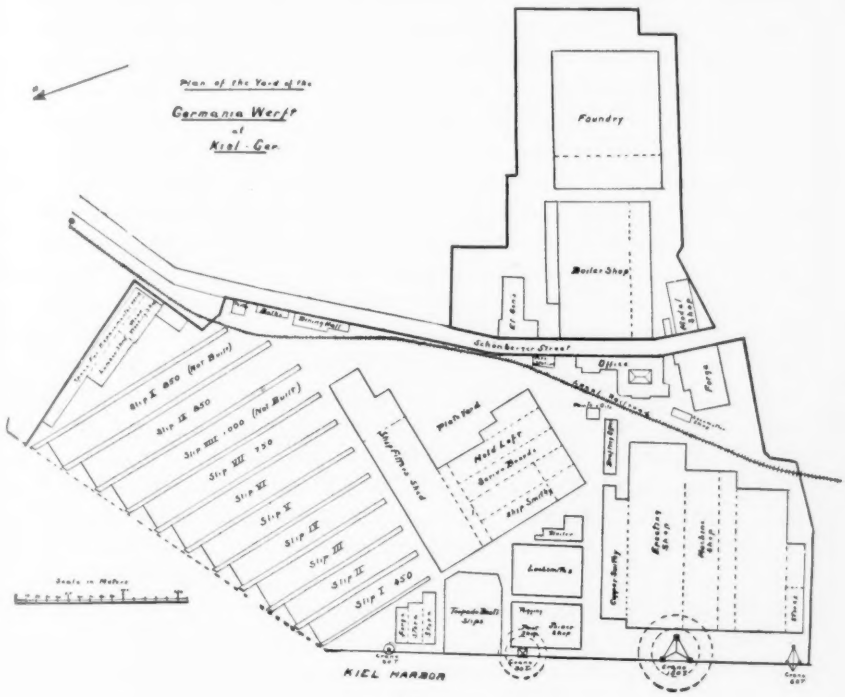


FIG. 3

tioned, which serves to place the engines on board the ships. A small power hammer shop lies behind the machine shop, next to the administration building. Large forgings come from the Krupp Steel Works at Essen.

As shown by the plan, this yard is bisected by an important public street, beyond which are placed the boiler shop and foundry, in land that has been excavated down to the yard level. The boiler shop fronts on this street directly opposite the office building. It is provided with the

usual machinery for building large marine boilers, both of the shell and the water tube types. The shell riveting machines are set in pits 8 feet deep, so that they get the head room necessary without requiring a tower over them. There are two furnaces in this shop for heating plates that are either bent to a small radius or are made into complicated forms.

Beyond the boiler shop is the steel and iron foundry, a very large shop for making the largest castings required for marine engines. It has several bays, each served by traveling cranes, and there are a number of post cranes among the columns that divide the bays. These latter are built up of angle bars and plates, and appear clumsy in design.

The pattern shop and the electric station are on the public street, on either side of the boiler shop.

Two evidences of the liberal views of the management are shown by the admirable provisions for bathing houses and eating houses for the employees, and by the large space assigned, near the north boundary of the yard, to the testing department.

The two most noted localities for shipbuilding in Great Britain are the northeast coast and the Clyde. Four of the leading yards which have individual characteristics were visited in each locality.

The first English yard to be visited was that of William Doxford and Sons, at Sunderland, which is especially interesting because they build only one special type of ship in large numbers, and consequently may be said to *manufacture* ships. This type of ship, which was suggested by the whale-back ships of the Great Lakes, has the topsides drawn sharply in above the water line, and the sides are then carried up vertically with a width about half the beam of the ship. They are all freight ships, with accommodations for only the officers and crew. A member of the firm who showed the yard gave the information that they could build ships at the rate of two a month, and that a ship could be launched in fifteen weeks if there were no delays. The engines and boilers are finished in anticipation of the launching of the vessel to which they belong, and are loaded on flat cars a day or two in advance. Immediately after the ship is launched these flat cars are run down to the finishing slip in proper order, and the material is placed aboard by a 50-ton crane. Two days are sufficient to get all the machinery installed and to get steam up. The joinery work, which is plain and small in total amount, is also ready, and the ship can soon be ready for sea. If a ship is launched in the morning, the ground is at once cleared and the keel for the next ship is immediately laid with material already prepared.

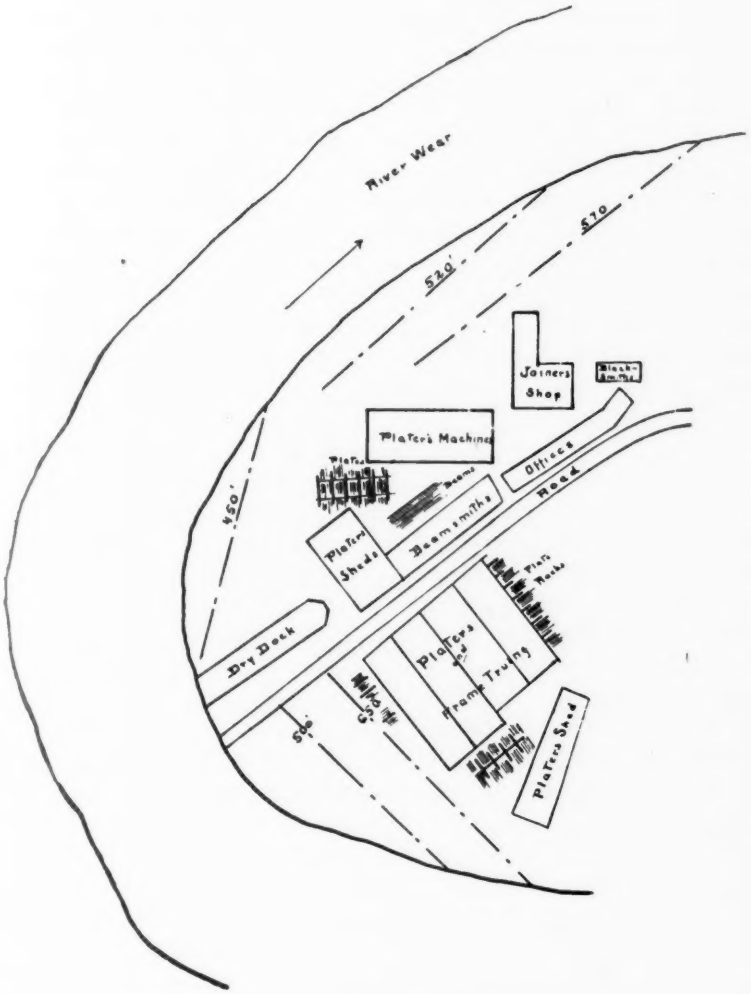
A large portion of the body of the ship is straight work with identical framing, a condition which lends itself to the method which originated on the Great Lakes, of laying out frames to a templet and assembling them and riveting them before they are sent to the slip. In consequence, the building can go on with great rapidity.

This yard, which lies along the Wear, has considerable water front, but is very narrow. When it was necessary to enlarge the yard, land down stream was secured; and as the land rose rapidly from the river, it was necessary to do much excavation to gain the space needed at the level of the yard. A line of rails runs on the edge of the bank above the yard, and the slope from the rails to the yard facilitates sliding material down to the level of the yard.

The fitting out wharf may be taken as the centre of the yard. It is a plain wharf barely long enough for one ship, so that where there are two ships fitting, as at the time of my visit, one must lie outside the other. The fitting crane is able to deliver boilers to the ship lying outside. The river, like most British streams, is narrow, and the building slips make a comparatively sharp angle with the margin of the river. There are three slips that point up stream and three that point down stream; the latter three, which are the newer, have overhead traveling cranes for handling material. It was said that the older slips were to be similarly provided when convenient. The advantage of such cranes was said to be rather in the saving of time than in direct reduction of expenses. It is probable that the conditions of manufacturng ships of one type are favorable for the introduction of mechanical devices, and such conditions are found in this yard and in the yards in our Great Lakes, where there is no question in the minds of those in control concerning the advantage of such devices. There is much difference of opinion concerning the economic advantage of elaborate mechanical systems of transportation in yards where the conditions are different. Over each of the slips which was provided with traveling cranes there were four longitudinal members in the roof or overhead structure, the whole length of the slip starting at the water's edge and running far enough beyond the inshore end to reach conveniently material brought to the head of the slip. On each of these longitudinal members there was a trolley driven by electricity, which carried a jib with a reach of somewhat more than one-eighth of the width of the slip measured to the row of posts supporting the overhead structure; thus all parts could be served by at least one of the trolleys. Heavy weights could be carried

by one, two, three, or all four trolleys, as might be convenient. Through the yard was a convenient system of rails at the usual gauge on railroads, so that material could be brought from outside or from any shop to the required place. There were also a number of locomotive cranes, found also in some other British yards; for example, at Armstrong's yard at Newcastle. The external appearance of one of these was not unlike a small locomotive, with a dome over the fire box, in which was a vertical cylinder looking upwards. The crosshead at the end of the piston rod slid in vertical guides, and was connected directly to the short end of a horizontal lever, or crane-arm, reaching beyond the front end of the locomotive; the fulcrum of this lever was supported by links from the frame of the locomotive, so as to give the required flexibility to the linkage. These cranes were said to be convenient and rapid in action and could be used to draw cars like ordinary locomotives. It may, however, be said that the same type had been tried in other yards and rejected in favor of the more ordinary locomotive crane with small vertical boiler and swinging jib.

Each group of slips has its own bending slab and ship tool house, an arrangement which is favored by the configuration of the yard, and which came naturally with the extension of the yard in a narrow space between the river and the railroad. Angles and other bars and beams are delivered from flat cars on the line of rails on the bank above the yard, and are slid down to the bending slabs; as there is little variety of such material the handling is simple. The plate yard is above the building slips, just below the same line of rails. The machine shop and boiler shop lie side by side and adjacent to the office building up stream, beyond the older building slips. They are supplied with the most recent and powerful machines, it being the policy of the company to replace any machines by a better one when that appears advisable, no matter how recent the condemned machine may be. In the process of supplying the machine shop with modern tools it was found necessary to import some tools from America before the British tool builders could be made to build the tools desired, but when the British equivalents were available they were preferred because they were stiffer. The machine shop is of the usual form, with a wide central bay served by traveling cranes, and with two side aisles over which there are galleries for small tools. The large tools on the floor were drawn well back into the side aisles, so that the main bay was available for material in hand. There has been much increase in the rate of machining engines and other parts in the



Sketch Plan of Yard of
Sir James Laing & Sons at
Deptford
Not to Scale

FIG. 4

last two years, which was made possible by the improvement in the steel used for cutting tools. At the time of my visit there were six engines of one pattern in process of erection, and as many more in course of construction.

Down stream from the yard of William Doxford and Sons, at Sunderland on the Wear, is the yard of Sir J. Laing and Sons, which is engaged in building high class passenger and freight ships, scarcely two of which are quite alike. The conditions of building ships in this yard are almost the converse of those in the yard just described, and the peculiar relation of the yard to the river into which the ships are launched emphasizes the difference. They have five slips in all, as shown on the accompanying sketch (Fig. 4), and they can build seven ships in a year, which, considering that many of the ships are much larger and that the fitting is likely to take more time than the building of ships of this class, is no less creditable than that of the yard just described.

As will be seen from the sketch, the yard lies in a bend of the river nearly a semicircle in extent. The building slips are distributed in what looks at first sight like an erratic manner, but which is demanded by the configuration of the water front, bearing in mind that the ships must be launched into a narrow stream. This arrangement of the slips throws the various shops into a group in the centre of the yard, which makes the transportation of material and the superintendence of work comparatively easy, even though there is no special method of handling material. It may be noted, also, that there are no engines or boiler shops, which further simplifies the conditions. A wagon road runs across the yard past the offices and shops down to the dry dock. There is one large shop for bending frames and for working plates, and three smaller shops for plating work, with plate stakes adjacent; and there is also a shop for smithing beams. These, with the blacksmith shop and the joiner shop, complete the outfit for this yard. At one of the slips they have a number of steel derricks built of angles and plates for hoisting materials to the ship, and through the open bases of these derricks they have a Temperly conveyor, consisting of a system of trolleys on an overhead rail drawn by a continuous wire rope. The other slips have wooden derricks, without any special method of transportation of material.

A very interesting set of observations were made on a ship during launching in regard to the conditions of hogging and ragging at different periods of the launch. These observations were facilitated by the arrangement of the deck houses, which had a break near the middle of

the ship. During wedging up, to bring the weight of the ship on the sliding ways, there was a little sagging. As the ship slid down the ways this sagging at first increased, then diminished, and changed to hogging as the ship became water-borne. At the leaving of the ways there appeared to be considerable vibration or rapid changing from sagging to hogging.

The establishment of Sir William Armstrong, Whitworth and Company, at Elswick on the Tyne, near Newcastle, is most noted for its extensive ordnance and armor-plate works. The extensive shops of this part of the establishment are on the bank of the Tyne, at various levels, as the configuration of the ground makes necessary. The shipyard on a narrow flat at the river's edge is an old yard, somewhat inconveniently arranged in consequence of its compression between the river and the ordnance shops on the bank, and further appears at some disadvantage in consequence of old and poorly arranged and lighted shops. A public road, which formerly ran between the yard and the ordnance shops, has recently been acquired by the company, and extensive improvements are in progress.

The ordnance and armor works of this company early placed them in position to build warships complete, with armor and guns, and their reputation has been widely extended by a number of remarkable ships of great power and speed for their displacement. Such ships have been bought by foreign nations, especially those that were unable to build for themselves, and which, to meet special conditions, found it desirable to be able to show large offensive power in proportion to their expenditures. The company has also built many ships for the British Admiralty and for foreign nations, which fill every requirement for service under all the ordinary conditions of powerful navies. It is most remarkable that this company has furnished two chief constructors to the British Admiralty, the one now in charge of the construction department and his predecessor. Both were trained in the government dockyards and at the Royal Naval College, and both loyally responded when the Admiralty needed their services.

This yard has four slips suitable for building large ships, two of them with a large slant down stream and two with the same slant up stream, this arrangement being due to the narrowness of both the yard and the river. The bending slabs and ship tool house are between the slips and the plate yards are outside the slips. Transportation within the yard is mainly on rails having the standard gauge, and largely by locomotive

cranes, already described in connection with the report on the yard of William Doxford and Sons. Three locomotive cranes bring material within reach of wooden derricks ranged alongside of the slips. All side armor is placed on ships by these derricks before launching.

It is the habit at this yard to assemble the armored deck of a warship in the mold loft and to templet all the topsides above the armored deck in the loft, so that this material can be ready in advance and thus facilitate construction. All framing behind armor is treated in a similar manner. Large holes are left where armor bolts are intended to be located, to allow the bolts to come or go as the sockets for them in the armor may require. Small plates are fitted over the bolts to cover these holes, and are riveted to the framing behind armor after the armor is in place. The system of templeting is carried to a large extent, the company making the templet instead of allowing the ship fitters to make templets for themselves, as is a common custom. At the time of my visit a large cruiser was building under secret service, so it could not be examined or even approached too closely; the same condition was found in another yard; but as special permission is required to examine warships under construction in private yards, whether building for the Admiralty or for foreign nations, and as that permission is always difficult, the only special interest was that not even the ownership of the vessel was given. Both ships have since proved to be ships carrying eight 12-inch guns, with a speed in excess of that of the *Dreadnought*. Though called cruisers, they are more powerful than any battleships now in active service. This cruiser was reported to have two rudders, so that a stern torpedo tube could be installed; the stern port consequently becomes a bent structure made of ⅞ or 1 inch plating. These ships are reported to carry the guns in turrets so arranged that four guns could be trained directly forward and two directly aft, while all eight can be trained on either broadside; and as no guns fire over another gun station, it is probable that the inboard turrets are arranged *en échelon*. This report is of interest in that the American arrangement of two central line turrets forward and two aft was spoken of with approval, it being said that such a device had been in part worked out though never applied. Another item of interest is that in ships built for the Japanese navy the magazine for cartridges was placed beneath the shell rooms, as the latter were found the more susceptible to explosion by external mines. To guard against the influence of mines, a 60-pound plate was worked under the magazines.

The yard of Swan and Hunter, at Wallsend, was the last one in this neighborhood to be visited. The general arrangement of this yard appears to have grown up with the growth of the yard, which is now combined with the adjacent yard of Wigham and Richardson, and does not present any notable feature, except that the yard appears too restricted in width for the very large ships under construction, which reach from the water front to the inland boundary wall. The most interesting features of the yard were the large glazed ship sheds over the largest ships. These sheds carried traveling cranes of the types described in connection with the yard of William Doxford and Sons, namely, a number of trolleys run the length of the shed, each with a swinging jib crane. This type of crane was designed for this yard by an American firm which builds hoisting machinery. At one side of each slip the ship house had a wide aisle, in which were the ship tools for serving that ship—a very convenient arrangement, made possible by the extent of their water front, and believed to be unique. It called to mind the method, first seen at La Seyne, of placing ship tools in the open between ships.

At this yard the ships are faired on marble slabs, only the scrive board and stem and stern being left for construction on the mold loft floor. A very large table was prepared for the large turbine Cunarder, which was then on the stocks. They had also tried opal glass without satisfaction, samples being shown which were thin and with too smooth a surface, on which the ink ran. It is interesting to compare this with our own successful experience with a very thick opal glass, which had a surface ground to conform to our specifications after trying samples. This glass is very strong, takes pencil and ink lines readily, and can be cleaned with ordinary soap and water, while a special powerful soap is required for marble. This glass is also much cheaper than marble, and obtainable in very large slabs.

The Fairfield Ship and Engine Company's yard, at Govan, on the south bank of the Clyde, is a good example of an established yard that has grown with the growth of shipbuilding and has been reconstructed to meet growing requirements. The arrangement of the yard is determined by the direction of the river front, which here runs somewhat to the north of west, with a turn toward the north at the lower end of the yard. As the river is narrow, the building slips have a sharp slope down stream, and extend nearly from the eastern boundary of the yard to the northwest corner; beyond the slips is the fitting basin, at the northwest corner of the yard. This arrangement leaves a triangular space at the northeast corner of the yard, which is used as the storage for plates,

frames, and beams, and which is served by two gantry cranes, one running at right angles toward the water fornt, and one parallel to the water front. The ship tool house with bending slabs, etc., lies across the inner end of the slips, so that material comes conveniently from the plate and frame store, and then is sent down to the slips. The engine and boiler shops are in the southwest corner of the yard, and the work from there goes northward down to the fitting basin. The cabinet and joinery shops, etc., lie between the building slips and the machine shop. There are two forge shops, one for the machine shop and one for ship work. Large forgings and castings are all made elsewhere.

The building slips are served by wooden derricks and electric winches, a method that is widely used in Great Britain. Material is brought from the railway station over the tramway rails by an electric locomotive that takes the current from the overhead trolley wires. The custom in this yard is to lay down all the ship's lines in the mold loft, and to make templets from those lines to a very large extent.

The Leven Shipyard of William Denny and Brothers, at Dumbarton on the Clyde, is an establishment of moderate extent, arranged in a simple manner for doing work of high order in an economical manner. The fact that they established the first private experimental model station, and that they have used it for twenty-two years for solving new problems in shipbuilding, is a guarantee that all their methods are selected deliberately and with good reason. The only exception to this, if indeed it has been allowed to have a controlling influence, is the general arrangement of the yard to suit the configuration of the site. For example, the building slips are arranged to point directly up the river Leven, into which the ships are launched, and they consequently radiate from a point instead of lying parallel; the angle subtended by the slips is, however, not large. This arrangement might make it difficult to use overhead traveling cranes, but the company have a system which they consider to be more economical and more effective; namely, they have a system of narrow gauge rails for small hand trucks, which run through the yard and into the shops. This system is extended down the slips and is moved wherever necessary by a special gang of men. As soon as the double bottom of a ship is laid, one or more lines of this system are laid on top, and in like manner lines are laid on decks as soon as convenient; of course the trucks readily run down such lines, on account of the inclination of the building ways. At the side of each slip is a hydraulic derrick for heavier weights, and there is a complete service of wooden derricks and hydraulic winches. A casual inspection of the yard, especially if

there should be no ship at a stage of construction that would show the system, might lead to a hasty conclusion that the yard lacks a transportation system. In addition there is a system of rails of standard gauge, with locomotive cranes of the usual type.

The system of templeting in the mold loft is carried to a considerable extent, but is supplemented by laying out the plates for bulkheads on the scrive board and making them so that they can be punched without using templets. To show that the system is capable of rapid work, it is said that the yard built a freight ship of good type, with some passenger accommodations, for the volunteer fleet of Russia, in six months.

The yard of John Brown and Company, at Clydebank, is another example of growth which has resulted in an apparent lack of system of storage and transportation of material. They have, however, a system of rails of standard gauge with locomotive cranes, and use the same method as at the Leven yard, of narrow gauge rails and hand trucks. Save for this feature (if indeed it is allowed to seriously interfere with the efficiency of work) this yard has the most modern methods introduced wherever they are considered advantageous. For example, they have an extensive application of direct electric driving of large tools of all sorts, and of groups of small tools, and they use converter gas for heating and power. They are equipped with large and accurate machinery for building steam turbines both for their own ships and for other builders, and had, at the time of my visit, a large amount of work in hand in all stages, so that there was a good opportunity to see the construction of large marine turbines of the Parsons type, including turbines for the large Cunarder now under construction. Incidentally it may be mentioned that in the construction of these monster ships European builders consider it essential to do a large part of the hull riveting with portable hydraulic riveters, and that a large stack of them was seen in the yard. The climate on the Clyde, though frequently inclement, does not give such low temperatures as are common on our seaboard, and there is no difficulty in using hydraulic transmission of power.

At this yard they depend mainly on laying down the ship's lines on the mold loft floor, though they have a marble slab which they have used to some extent for smaller work.

There was installed at this yard two years ago an experimental mold basin closely copied after that at Haslau, as is described in another report.[1]

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[1] TECHNOLOGY QUARTERLY, 19, No. 4, December, 1906, pp. 339–353.

One of the most interesting features of this yard is the production of converter gas for the heating furnaces and for generation of power in internal combustion engines of large size, which drive dynamos for the system of electric transmission of power. The essential feature of this system appears to be the use of a cheap coal with a considerable percentage of nitrogen, as much as 3 per cent. being considered essential for economical operation of the plant. This nitrogen, which is recovered as a by-product, is used as a fertilizer, and has the effect of reducing the net cost of coal from a dollar and a half to seventy-five cents a ton. The coal appeared to be a fairly clean bituminous variety, broken quite uniformly into rectangular pieces about half an inch square. This low fuel cost, with the small consumption by internal combustion engines, reduces the cost of power to a very low figure, and there is a corresponding advantage in the use of gas for heating furnaces.

The establishment of William Beardmore and Company, at Dalmuir on the Clyde, is a good example of a modern shipyard laid out *ab initio* with all modern appliances. The plan of this yard shows that it occupies a narrow strip of land over a mile long between the river and the railway. The yard is scarcely yet completed, and has done comparatively little work, so that it appeared under somewhat unfavorable condition at the time of my visit. Of the six slips shown on the plan, only one was in complete working order, and on it was a battleship for the British Admiralty. It had an overhead crane system without a roof, there being two traveling cranes to serve the two sides of the ship, and also a number of jib cranes distributed on the sides of the framework, under the traveling cranes. There were also two comparatively small ships, one each side of the battleship, without any special system for handling material.

The very extended water front (Fig. 5) gives a considerable dispersion to the various elements of the yard, but the arrangement shown appears otherwise to be very convenient. Thus the timber sheds are in the most remote section of the yard, together with the sawmill and timber pond; a fire in this region could easily be localized. The angle bars are stored at the right and the plates at the left of the building slips, while the bending slabs, ship tool house, and shipsmith shop, etc., are along the boundary in front of the building slips. The fitting basin is toward the western end of the yard, and around it are grouped the woodworking and plumbers' shops and stores on the right, and the machine and boiler shop at the left, with the central power station intermediate

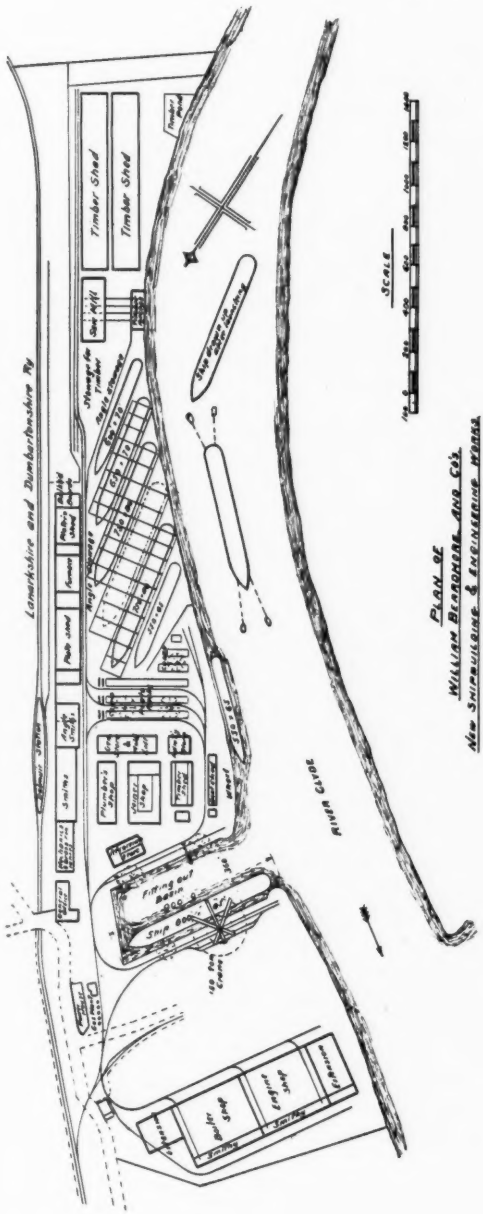
Lanarkshire and Dumbartonshire Ry
Timber Shed
Timber Shed
Fitting out Basin
Ship Room
River Clyde
Scale
Plan of
William Beardmore and Co's
New Shipbuilding & Engineering Works
Dalmuir Scotland

FIG. 5

between the various shops that require power from the system of electric distribution. There is room in the fitting basin for two large ships, and a third can lie at a wharf near the woodworking shops. At the basin is a crane for putting engines and boilers, etc., on board. This crane is a cantalever crane, with a short arm that can lift 150 tons and a long arm with great reach that can lift 50 tons.

The engine and boiler shops are in one immense, lofty building that is as yet unfinished. At the time of my visit the boiler shop was not divided from the engine shop, which was in consequence open to the noise and dirt of the former; but that may be a temporary arrangement. There was a provision of traveling cranes, and all large tools were driven by direct electric transmission. This yard, like that of John Brown and Company, has the converter system of making gas for heating furnaces and for power. Some of their engines generate a thousand horse power in four cylinders, having the pistons connected to two cranks.

The last yard visited was that of Harlan and Wolff, at Belfast. It is an old yard, noted for building ships of the largest size. Being situated on the bend of a river, it has some building slips looking up stream and some looking down stream; the plate and angle stores and the various shops lie between or along the street front. The engine shops are on the opposite side of the street. This yard was the first to introduce hydraulic riveting of the frames of large ships, and for this purpose placed over the slips lofty gantry cranes for carrying the portable hydraulic riveters. Two of the slips have an overhead cantalever crane of the Brown Hoisting Machinery type, which has the peculiarity that on each side under the cantalever crane there are traveling bracket cranes that can carry hydraulic riveters. Up stream from the building slips are several fitting slips or wet basins, and also a dry dock.

DETERMINATION OF SULPHUR IN PYRITE[1]

By HENRY FAY

I. Available Sulphur — Lunge Method

Spread out on the bottom of a 200 cc. casserole 0.4 to 0.5 gram of pyrite which has been ground to extreme fineness. Pour over this 20 cc. of a freshly made mixture of three volumes nitric acid (sp. gr. 1.42) and one volume hydrochloric acid (sp. gr. 1.20). Cover the casserole with a watch glass and warm gently until action commences; then remove from the heat until action slackens. Start the action again from time to time and remove from the heat when the oxides of nitrogen begin to be evolved. In this way continue the heating until all action has apparently ceased. Complete disintegration should be accomplished in five to ten minutes. If sulphur separates it is probable that the reaction was allowed to proceed too violently, or that the pyrite was not ground finely enough. In case sulphur has separated it is preferable to start with a new sample rather than to try to oxidize the separated sulphur by the addition of potassium chlorate.

When disintegration is complete add 5 cc. of sodium carbonate solution, and evaporate to dryness on the steam bath. Pour over the dry mass 5 cc. of hydrochloric acid (sp. gr. 1.20) and again evaporate to dryness. Moisten the residue with 1 cc. of concentrated hydrochloric acid, warm gently for a moment, then dilute with 100 cc. of hot water. Filter, wash several times with hot dilute hydrochloric acid, and finally with hot water.

Pour the filtrate into a slight excess of ammonia and keep the mixture hot for ten or fifteen minutes. Filter through a 4-inch Swedish paper, wash first by decantation, and then, throwing the precipitate onto the paper, wash thoroughly with hot water.

If the filtrate and washings exceed 250 cc., acidify with hydrochloric

[1] Editor's Note. — From time to time it is proposed to publish, with critical comments, various analytical methods which have proved useful in the Chemical Laboratory.

acid and concentrate approximately to this volume. To the boiling, slightly acid solution add a hot solution of 5 per cent. barium chloride from a dropper, allowing the drops to run down the inside of the beaker until a slight excess has been added. Allow to stand in a warm place for half an hour, then filter, washing by decantation with hot water until the washings are free from acid, and then complete the washing on the filter until free from chlorides.

When the filter has drained as much as possible from wash water, fold it over the barium sulphate, and place it in the bottom of a weighed platinum crucible. Incline the crucible on its side, with the lid partially covering the front, and place under the front end a flame so small that it will dry the paper so slowly that there is no danger of spattering, and that it will char the paper without taking fire. When the paper is completely charred, place under the back of the crucible the full oxidizing flame of a Tirrell burner, and heat thirty minutes. As some of the barium sulphate is invariably reduced to sulphide, it is necessary to allow free access of air into the crucible, and to continue the heating until constant weight is obtained.

II. Total Sulphur — Fresenius Method

Mix 0.4 to 0.5 gram pyrite with ten parts of a mixture of four parts sodium carbonate and one part potassium nitrate in a platinum crucible.

Cut an opening in an asbestos board (at least 4 inches square) sufficiently large to allow the lower two-thirds of the crucible to project below the board. Place the covered crucible in this opening, heat gently at first, and finally raise the temperature enough to bring the mass to fusion. Any unnecessary increase in the heat should be avoided on account of the action of the oxidizing mixture on the platinum. Keep the mass in fusion fifteen minutes, stirring, if necessary, with a stout platinum wire to prevent the fusion from caking on the sides of the crucible.

When the action has apparently ceased, place the crucible in a porcelain casserole, and extract the residue several times with boiling water. Decant the solution through a filter paper and then boil the residue with 20 cc. of a 10 per cent. solution of sodium carbonate. Finally, wash the residue thoroughly with a 1 per cent. solution of sodium carbonate.

Make the filtrate distinctly acid and then add 5 cc. of hydrochloric

acid (sp. gr. 1.20) in excess. Boil to expel the carbon dioxide and evaporate to dryness. Moisten the residue with 5 cc. concentrated hydrochloric acid and again evaporate to dryness. Then warm the residue gently with 2 cc. of hydrochloric acid (sp. gr. 1.20) and add 100 cc. of hot water; filter, and wash the silica.

In the filtrate, which should amount to about 250 cc., the sulphuric acid is precipitated in boiling solution by hot barium chloride, as recommended above, and the barium sulphate should be filtered, washed, and ignited in the same manner.

NOTES

1. The very great commercial importance of pyrite makes the accurate estimation of sulphur one of the most important determinations in the whole field of analytical chemistry. For the determination of *available* and *total* sulphur, the methods of Lunge and Fresenius, respectively, are undoubtedly the most accurate. The Lunge method determines only that portion of the total sulphur which is available for the manufacture of sulphuric acid; the Fresenius method determines all of the sulphur irrespective of the form in which it exists. Very many other methods have been proposed, but none of them has met with such general favor as these two, and they can at this time be considered as standards for this determination.

2. If the reaction in the Lunge method is allowed to begin too vigorously there is invariably a separation of sulphur, and, while it is possible to oxidize the separated sulphur, it is only done at the expense of much time and after the addition of considerable potassium chlorate.

The Lunge method cannot be used for the decomposition of many of the native sulphides on account of the strong tendency of some of them to liberate their sulphur in the free state. By using pure fuming nitric acid, or by reversing the proportions of nitric and hydrochloric acids, the decomposition and oxidation of most sulphides may be accomplished successfully.

3. It is necessary in all cases, before precipitation of barium sulphate, to remove completely all traces of nitric or nitrous acids by repeated evaporation with hydrochloric acid. It was shown as early as 1842 by Mitscherlich that barium sulphate carried down many salts from solution; on the other hand, its complete precipitation is inhibited by the presence of certain salts. In either case, when an accurate determination of sulphur is to be made, the salts which interfere with

the precipitation must be removed before barium chloride is added to the solution. Among the more common substances which are carried down with barium sulphate are the chloride, nitrate, and chlorate of barium, sodium, and potassium; copper, zinc, iron, and aluminium salts. Some interesting experiments have been made by Hulett and Duschak,[1] showing the amounts of barium chloride actually carried down with the barium sulphate. They have also devised a very simple method by which corrections can be made for this error. The complete precipitation of all of the sulphuric acid in solution is interfered with by the presence of chromium salts, metaphosphoric acid, etc.

4. The precipitation of barium sulphate in the presence of ferric iron has received attention from a large number of investigators. It has been known for a long time that low results are obtained when barium sulphate is precipitated from solutions containing ferric iron, notwithstanding the fact that the precipitate is contaminated with ferric oxide. In the process of ignition sulphur trioxide is lost, and the amount lost more than counterbalances the weight of the ferric oxide. The old method of fusing the ignited precipitate, if it showed a red color, led to inaccurate results, although ensuring a purer precipitate. Some of the sulphuric acid was always lost during the process of ignition, the amount depending upon the time and temperature of heating.

Various remedies have been proposed in order to overcome the difficulty of the precipitation of barium sulphate in the presence of iron salts. These remedies may be classed under three heads:

(1) Removal of the iron before precipitation.

(2) Conversion of the ferric ion into a complex ion.

(3) Conversion of the ferric ion to the ferrous ion.

The Fresenius method is the best representative of the first principle. In this case the iron is completely removed as the oxide, and, after the subsequent removal of nitrous and nitric acids by evaporation with hydrochloric acid, the precipitation may be carried out under the most favorable conditions.

In the Lunge method this same result is reached by precipitation of the iron by means of ammonia. Many chemists have claimed that this precipitation of ferric hydroxide always gave inaccurate results on account of the retention of basic iron sulphate in the ferric hydroxide precipitate. Lunge has repeatedly expressed the firm conviction, however, that if the method is carried out as he directs there will be no loss

[1] Zeit. für Anorg. Chem., **40**, 196.

on this account. Gladding[1] modified the method so as to obviate the tedious washing of the ferric hydroxide precipitate. He recommended to redissolve the ferric hydroxide in hydrochloric acid and then the addition of barium chloride to this solution to recover the small amount of sulphuric acid carried down.

The most interesting modification of the Lunge method involving the same principle is that of Küster and Thiel.[2] They advised the precipitation of the ferric ion by an excess of ammonia and the addition of barium chloride to this solution, dissolving the ferric hydroxide after the complete precipitation of the barium sulphate. This method overcomes the objection raised by Gladding, in that it removes the iron from solution, and furthermore it does away with a troublesome filtration. The results obtained by this method are undoubtedly higher than those obtained by the Lunge method. Whether or not this is due to a certain counterbalancing of errors remains to be seen after further experiments have been tried. It is highly probable that the occlusion of barium chloride by the precipitation of the barium sulphate in the ammoniacal solution would be considerable. Lunge[3] has recently admitted and shown by a series of experiments that his own method gives accurate results only because of a counterbalancing of errors.

The conversion of the ferric ion into a complex ion was first suggested by Jannasch and Richards,[4] who used for this purpose formic, acetic, and citric acids, and this was extended by Küster and Thiel,[5] who used oxalic and tartaric acids; but in neither case were the results entirely satisfactory, as the precipitates were invariably colored by occluded iron.

The conversion of the ferric into the ferrous ion also originated with Jannasch and Richards,[6] but the results by this method have not been entirely satisfactory. When zinc and hydrochloric acid are used for the reduction, the zinc in solution is always carried down by the barium sulphate. In the hands of some chemists this method has been more satisfactory, although it has not come into general use.

No completely satisfactory explanation has yet been offered as to why barium sulphate carries down iron salts nor why solutions contain-

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[1] J. Amer. Chem. Soc., **16**, 401.
[2] Zeit. für Anorg. Chem., **19**, 98.
[3] Zeit. für Angew. Chem.
[4] J. Prak. Chem., **147**, 325.
[5] Zeit. für Anorg. Chem., **19**, 101.
[6] J. Prak. Chem., **147**, 322.

ing iron salts will retain some barium sulphate. Some evidence has been offered by Jannasch and Richards[1] for the existence of a barium ferric sulphate, and this idea has been subjected to experimental study by Schneider,[2] who came to the conclusion that a solid solution of low concentration was formed. On the other hand, Ostwald[3] has called attention to the analogy with chromium salts, which on heating form a complex ion containing the SO_4 group, which does not react with barium ions. Küster and Thiel[4] developed this idea and assumed that some such complex as $Ba[Fe(SO_4)_2]_2$ is formed, but they admit from the data at hand that it is impossible to say what is the nature of the complex. It seems probable that the true explanation will be that barium sulphate is capable of forming a solid solution with some product of the hydrolysis of ferric sulphate.

5. The explanation of the occlusion of barium chloride is very much more satisfactory. Hulett and Duschak have carefully determined the amounts of barium chloride carried down by barium sulphate under varying conditions, and have offered an explanation of this occlusion which seems to be satisfactory. They have found that barium sulphate carefully washed and dried at 140° contains not only barium chloride, but also chlorine in some form of combination which splits off hydrochloric acid at higher temperatures. Reasoning by analogy, they assume that barium chloride may, like lead and mercuric chlorides, dissociate not directly into Ba and Cl ions, but the dissociation may take place in this way:

$$BaCl_2 \rightleftarrows BaCl^{\cdot} + Cl'$$
$$BaCl^{\cdot} \rightleftarrows Ba^{\cdot\cdot} + Cl'.$$

In like manner sulphuric acid may also dissociate:

$$H_2SO_4 \rightleftarrows HSO_4' + H^{\cdot}$$
$$HSO_4 \rightleftarrows SO_4'' + H^{\cdot}.$$

On the assumption of such partial dissociation, $BaCl^{\cdot}$ ions could combine with HSO_4' ions to form the salt $BaCl.HSO_4$, which, upon being sufficiently heated, would split off hydrochloric acid and leave neutral $BaSO_4$. Hulett and Duschak also assumed the possibility of such reactions as the following to take place:

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[1] J. Prak. Chem., **147**, 332.

[2] Zeit. für Phys. Chem., **10**, 425.

[3] Zeit. für Phys. Chem., **29**, 340.

[4] Zeit. für Anorg. Chem., **25**, 322.

$$\text{I.}\quad 2BaCl^{\cdot} + SO_4'' \rightleftarrows \begin{matrix}BaCl\\BaCl\end{matrix}\!> SO_4.$$

$$\text{II.}\quad 2HSO_4' + Ba^{\cdot\cdot} \rightleftarrows \begin{matrix}HSO_4\\HSO_4\end{matrix}\!> Ba.$$

When the salt $\begin{matrix}HSO_4\\HSO_4\end{matrix}\!> Ba$ is heated it should give off sulphuric acid and leave barium sulphate; when heated together with more than the equivalent of $\begin{matrix}BaCl\\BaCl\end{matrix}\!> SO_4$, hydrochloric acid should form; and when heated with less than the equivalent, then we should expect both hydrochloric and sulphuric acids. This condition was actually realized by Folin,[1] who studied the conditions under which either one or the other of these two salts should form. He also suggested the possibility of formation of salts of the character represented by the formula $\begin{matrix}M'SO_4\\M'SO_4\end{matrix}\!> Ba$ in which M represents any metal. This would account for the carrying down of potassium when barium sulphate is precipitated in its presence.

6. Too long and too high heating of the fusion in the Fresenius method will cause considerable attack upon the platinum crucible, and consequently the introduction of platinum into the analysis. If other constituents than sulphur are to be determined, this fact must be taken into consideration, and the platinum removed accordingly.

The completeness of the reaction may be judged by the appearance of the residue after fusion. It should have the color of rouge. If black, it will contain ferrous sulphide.

The use of coal gas for heating the crucible is almost unavoidable in a large laboratory, but in small laboratories the use of an alcohol lamp is strongly advised. The deflection of the products of combustion by means of an asbestos board partially overcomes the difficulty.

That barium sulphate is easily reduced to sulphide during the process of ignition is not sufficiently recognized. As much care should be used in the ignition of this precipitate as in the ignition of magnesium ammonium phosphate.

It should also be remembered that under no circumstances is it permissible to heat barium sulphate over the blast lamp. Above 900° it loses sulphur trioxide, and the residue becomes alkaline, owing to loss of sulphur trioxide.

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[1] J. Biol. Chem., 1, 131.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION

A METHOD FOR TESTING AND COMPARING SEWAGE SPRINKLERS[1]

BY EARLE B. PHELPS

IN the application of sewage to the surface of filters of the trickling or sprinkling type, evenness of distribution is an essential factor. This is more especially true in the case of filters whose material is of so coarse a nature that there is little or no lateral movement of the sewage within the bed. If on such a filter one-third of the surface is receiving two-thirds of the applied sewage, it is quite evident that the rate of filtration on that area is twice the mean rate. This rate would largely determine the character of the effluent, and an effluent of the same character could be obtained at twice the rate of filtration if the sewage could be distributed in a perfectly even manner over the whole area.

To accomplish this distribution over the surface of coarse-grained filters, many types of distributor have been devised. Among the more important of these may be mentioned: (1) Systems of fixed troughs, designed either to overflow or to discharge through notches or orifices; (2) delivery arms rotating over circular beds, operated either by the flow of the sewage or by power, distributing through nozzles or by overflowing; (3) large overflow troughs moved laterally back and forth over the bed; and (4) fixed sprinkler heads (pressure sprinklers) discharging upward under pressure, or discharging downward (gravity sprinklers) upon sprinkling or spattering disks. The distribution effected by these various methods is necessarily more or less uneven, and the efficiency of a given system may be defined as the evenness of the resulting

[1] Reprinted from Engineering News of October 18, 1906, LVI, 410–411.

distribution, a perfect distribution being one in which each small unit of area is receiving its proportionate share of the sewage. Such a condition is approached, in theory at least, by well-designed distributors of the second and third types enumerated. Their efficiencies depend upon proper leveling, unobstructed openings, and other details of design and operation which need not be gone into. Distributors of the first type mentioned cannot give perfect distribution. They distribute in lines, and as these lines are brought nearer and nearer together the distribution becomes more nearly perfect. In the Stoddart distributor the limit is reached and almost perfect distribution achieved by completely covering the filter with corrugated sheets of metal, the individual troughs being in actual contact. It is with the last group mentioned — pressure and gravity sprinklers — that the present discussion has to deal. Such sprinklers are fixed at definite points at or above the surface of the bed, and are designed to throw the sewage in a spray or spatter over the intermediate areas. The efficiency of their distribution under given conditions of head is determined entirely by their design, and the study of this efficiency is one which lends itself readily to careful experimental methods. The distribution is obviously not a perfect one, if for no other reason than that it is circular, and there must either be overlapping of the circles or intermediate non-wetted spaces, or both. Within each circle, moreover, there is generally a tendency to the formation of concentric rings of greater or less flow than the average, so that if small units of area are studied there will be found a variation in rate of flow along a radius. The definition of perfect distribution is one which is easily grasped, but the conception of a quantitative measure of the unevenness of the distribution is not so simple, and no attempt has heretofore been made to work out such a measure. Obviously the distribution is not measured by the wetted surface, although that expression is the best one which has thus far been used to describe the efficiency of a sprinkler. In the course of an investigation of pressure and gravity sprinklers now being made at this station, the need of some quantitative measure of the results was at once manifest. A mathematical analysis of the conditions involved was made, resulting in the definition of a "coefficient of distribution," which shows the mathematical relation between any observed condition of distribution and that condition which has been defined as perfect. In view of the ever increasing importance which sprinkling filters are assuming in this country, it is thought wise to publish this preliminary description of

the methods of testing employed and of the mathematical analysis of the results. A graphical representation of the conditions of distribution is first worked out, and from it the definition of the "distribution coefficient" is derived.

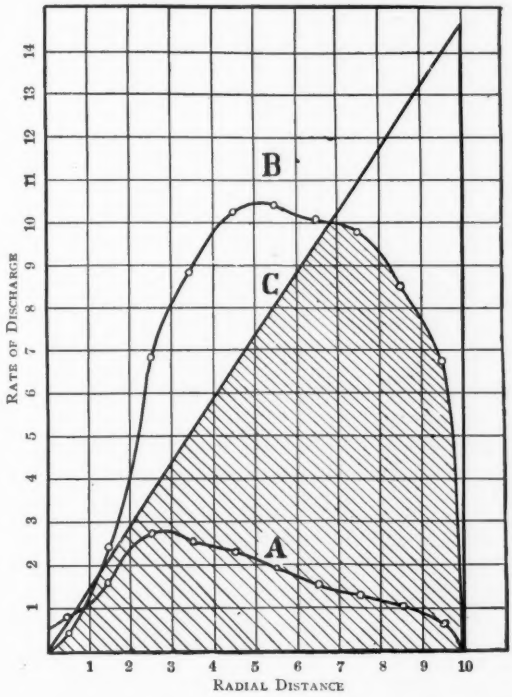
For the purposes of this problem let us assume that a pressure sprinkler is shooting up a spray of sewage, fountain-wise, the sewage falling over a circular area. Along any radius let us place a line of small, square collecting tanks of known areas, which we may designate the unit area. Let it be assumed, further, that the distribution along this radius is the mean of that along all radii. The variations along the various radii will be small, and the assumption may be completely realized, as is being done in our experiments, by revolving the line of collecting tanks about the centre during the experiment. After running a suitable length of time the sewage is shut off and the amount collected in each small tank is measured. In the accompanying table a set of actual results is reproduced for the sake of illustration.

TABLE SHOWING RESULTS OF OBSERVATIONS OF DISTRIBUTION EFFECTED BY SEWAGE SPRINKLER

Tank No.	Radial distance (D).	Sewage quantity (Q).	D × Q.	Excessive Quantities (Ex. Q).	D × Ex. Q.
1	0.5	0.8	0.4	. .	. .
2	1.5	1.6	2.4	0.14	0.21
3	2.5	2.7	6.8	1.24	3.10
4	3.5	2.5	8.8	1.04	3.65
5	4.5	2.3	10.3	0.84	3.78
6	5.5	1.9	10.4	0.44	2.43
7	6.5	1.5	10.0	0.04	0.26
8	7.5	1.3	9.8	. .	. .
9	8.5	1.0	8.5	. .	. .
10	9.5	0.6	5.7	. .	. .
Totals	50.0		73.1		13.43

$73.1 \div 50.0 = 1.46 = \text{M}.$

In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being



proportional to the volumes. Now if these quantities, Q, are plotted as ordinates against the corresponding D values as abscissæ, we obtain a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram. It shows the rate of discharge per unit area at any point whose distance from the centre is known, and will be known as the curve of radial distribution. Since the radial distribution measured was assumed to be the mean of all radial distributions, the ordinate of this curve at any given distance from the

centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i. e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing, relatively, by the radial distance of the point in question. In column 4, D × Q in the table, are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the corresponding D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

From its construction this curve has the following properties: the ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre; the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i. e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter. The base of the triangle is known, and from that and the area its altitude may be computed. It may be calculated more readily but less accurately by adding up the column Q × D and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area, which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the

more nearly will the two curves coincide and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves, differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

If we define the term "excessive discharge" as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form,

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities, $Q \times D$, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coördinate lines vertical, as usual, and the other set radiating from the origin. Direct plotting of the figures used in curve A upon such paper will in reality give curve B, any given value having an actual magnitude upon the plot which is proportional to the horizontal distance from the origin.

While the plot as thus worked out is essential to a clear understanding of the conditions and of the definition of the coefficient, it has been found much simpler and sufficiently accurate in practice to calculate the coefficient from the observed data (see table). Adding up the column $Q \times D$ gives the area under curve B, representing the total discharge (T). Adding the column D gives a number representing the

total wetted area; that is, it bears the same relation to the total area as the sum of the Q × D column does to the total discharge. Dividing the former by the latter gives the mean discharge (M) per unit area for the whole filter. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in the table under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column, they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total excessive discharge as already defined (E). We have now the two factors T and E for use in the formula,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

In the illustration used,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true coefficient based upon the total area of the filter, portions of which between the circles may not be wetted. Each sprinkler must then be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the final coefficient, C, may be found from the former coefficient, c, by the formula,

$$C = c \times \text{Cir/Sq}.$$

By the use of such a distribution coefficient it is possible to make experimental comparisons of both pressure and gravity sprinklers of various designs, and to test the effects of variations in head, rate of discharge, and other variables upon the distribution.

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BUILDING WARSHIPS BY CONTRACT; AND THE DUTIES OF THE SUPERINTENDING NAVAL CONSTRUCTOR[1]

By NAVAL CONSTRUCTOR A. W. STAHL, U.S.N.

WHILE general notions as to the proper composition of the fleet, and hence as to the character of new ships that should be built, are to a certain extent determined and settled by discussions in the various technical societies more or less directly interested and in the public press, as well as among naval officers in general, the formal and definite schemes for the actual ships to be built at any time are prepared by two boards in the Navy Department—one known as the General Board, and dealing largely with questions of strategy and war plans in general; and the other, the Board on Construction, consisting of the chiefs of certain Navy Department bureaus. When these two boards agree, their recommendation is practically always accepted by the Secretary of the Navy and transmitted to Congress; but when, as is unfortunately often the case, they disagree, the Secretary is under the necessity of coming to his own decision in the matter.

The Navy Department having recommended that certain ships be authorized, the matter is taken up by the Naval Committee of the House of Representatives. That committee gives hearings to the representatives of the Navy Department, as well as to others interested, and then recommends a certain building program for the session, this recommendation being necessarily influenced by many considerations other than that of obtaining the most efficient and necessary ships for the navy. The report of the committee is then considered by the House, which finally passes the Naval Appropriation Bill, in which bill are incorporated the descriptions of the ships to be built. This bill is then sent to the Senate, and by the latter body is referred to its own naval committee, which recommends that the Senate either concur in the bill, or, as is more usual, that the bill be modified in important particulars. The bill is finally,

[1] Lecture delivered to the Assistant Naval Constructors, at the Massachusetts Institute of Technology, Boston, Mass., December 8, 1906.

in some shape, passed by the Senate; and, if there are disagreements, it is referred to a conference committee between the two houses, and is finally adopted by both with a definite provision for certain ships.

The provisions enacted by Congress are not in detail, but simply in general terms, specifying the general character and size of each ship, its speed, and the limitation as to cost. Congress further provides whether the ship is to be built by contract or at a navy yard, and in some cases it gives the department the option as to these two methods of construction.

As soon as the bill has passed, the various bureaus of the Navy Department begin work on the plans and specifications of the particular ship or ships to be built. The plans are determined on, in a general way, by the Board on Construction, but the actual detail plans (except those of motive machinery) are made by the Bureau of Construction and Repair, being submitted from time to time to the board and modified as may be found necessary. At the same time, specifications are likewise prepared by the Bureaus of Construction and Repair, Equipment, Ordnance, and Steam Engineering. The Steam Engineering specifications are bound up separately; the specifications of the other three bureaus are bound in a single book known as the "Hull Specifications." In this book the Equipment specifications form a distinct and separate chapter, but the Ordnance requirements are simply embodied as a number of paragraphs in the Construction and Repair part. The plans and the specifications are finally approved formally by the Secretary of the Navy, and are then ready for issue to such shipbuilding firms as desire to bid on building the ship.

In the meantime, public advertisement has been made of the fact that on a certain day bids will be opened in the Navy Department for building the ship referred to; and the shipbuilding firms, who in response to such advertisement make application, are furnished by the Department with what is known as the "bidding circular." This circular recites the act of Congress authorizing the construction of the ship, and states the various limitations put on the size, speed, purchase of material abroad, price, etc., by Congress, and also gives the principal dimensions and other main features of the new ship. As soon as practicable, these builders are also furnished with copies of the specifications and plans of the vessel. The various shipbuilding firms then have their experts go over these plans and specifications, so as to become entirely familiar with the requirements of the prospective contract; and finally the men in authority

decide on the bid each firm will make. The methods of arriving at such bidding prices are different with every firm, and are governed by many other considerations besides the mere cost of the work to be done.

On the date specified, the bidders assemble at the Navy Department; and all bids are opened and read aloud in the presence of the bidders, the Secretary of the Navy, the Judge Advocate General, the chiefs of some of the bureaus, and other interested persons. If all the bidders base their bids exactly on the Government plans and specifications, the awarding of the contract is a very simple matter, as the law requires it to be awarded to the lowest responsible bidder; but this simple state of affairs does not usually exist. The bidding circular usually permits, or even invites, bidders to submit their own plans and specifications in competition with those of the Government; or, if not desiring to go to that extent, to propose modifications of the Government's plans or specifications, in each case giving their bid in connection therewith. When this condition of affairs exists, it is necessary, before the contract can be awarded, that careful study be given to the various propositions submitted by the bidders, in order that it may be determined which of these propositions, if any, it is to the advantage of the Government to accept. For this purpose the plans, specifications, and bids are referred to the Board on Construction, and by this board the various propositions are thoroughly examined. The board finally makes a report to the Department, recommending that the contract be awarded to some particular firm, on the basis of some definite proposition and price; and unless there be some exceptionally strong reason to the contrary, the board's recommendation is approved by the Department and the contract is formally awarded to the firm specified.

The next step is the signing of the contract; on the part of the Government by the Secretary of the Navy, and on the part of the contractors by the president or other duly authorized officer of the firm.

As soon as the contract has been signed, the Navy Department appoints certain officers as Superintending Constructor, Inspector of Machinery, Inspector of Equipment, and Inspector of Ordnance, in connection with the building of the vessel. Where the firm is already building some ships under contract, the various inspectors already on duty are always appointed for the new ship.

As soon as the contractors have signed the contract, the hull contract plans and specifications are sent to them through the superintending constructor, while the corresponding machinery plans and specifications

are furnished through the inspector of machinery. The contract plans are forwarded in the shape of Van Dyke prints. The superintending constructor first marks and signs these Van Dykes so that they can be identified at any future time. He then makes, in his own office, several sets of prints, after which he forwards the Van Dykes to the contractors.

The work of building the ship is now ready to be proceeded with, both the contractors and the constructor having the contract plans and specifications. Of the constructor's duplicate sets of prints, one is filed away as the official copy of the contract plans; the others are used for checking purposes.

The first thing done by the contractors is to have a very careful comparison made between the bidding plans and the contract plans; for although in theory these two sets of plans are identical, yet in actual practice it sometimes happens that modifications have been made before the contract plans are actually issued. Similarly the specifications are carefully scrutinized, and especially so the one particular copy which is marked and considered as the official contract specification. This would seem almost unnecessary, but in my own recent experience a case occurred in which some twenty or thirty pages had been accidentally left out by the binder from the particular copy of the specifications which was considered the contract copy.

If the contractors had reasonable grounds for expecting to get the contract, their drafting room would have the main requisitions for material all prepared and ready to send out by the time the contract was signed. The reason for this haste is that in the present state of the steel industry it is a matter of great difficulty to get early delivery of material, and hence it is very important to order the material at the earliest possible moment. These requisitions for material, as well as all the many others that must be prepared later, are submitted by the contractors to the constructor; and if they cover material to be inspected at the place of manufacture, the constructor forwards them to the Bureau of Construction and Repair. The purpose of this procedure is, first, to acquaint the Bureau with the status of the work and with the kind of material the contractors are preparing to use; and, second, so that the Bureau may appoint an inspector at the steel mills or other place of manufacture to examine the material as it is produced. At the same time the contractors send another copy of this requisition direct to the manufacturing firm, with their order for the material. When material is ordered by the contractors on the basis of a plan which has already been approved by

the constructor or by the Bureau, the Government cannot subsequently make any changes in the plan which will render any part of the material useless, without at the same time paying the contractors for the extra expense thereby caused them. If, however, as is frequently the case, the contractors submit their requisitions for material before the particular plans have been approved, then these requisitions are forwarded with the distinct understanding that any responsibility for the failure of the requisitions to agree with the plans as they are finally approved must be borne by the contractors.

While these early requisitions for material have been prepared, the contractors' drafting room has been busy on the fundamental drawings showing the general arrangements and details of the main structural work. The general layout of such work is usually fairly well defined in the contract plans and specifications, but there is always a clause in the latter which makes it obligatory on the contractors to provide ample strength; and it is at this point that the first conflict between the contractors and the constructor is liable to occur.

The main duty of the superintending constructor is to see that the ship is built in accordance with the contract; and this duty may be broadly divided into two parts: first, to see that the plans issued to the contractors' yard set forth correctly the work to be done; and, second, to see that these plans are adhered to in the actual building of the ship.

The specifications require that no work shall be done except in accordance with duly approved plans; and they further stipulate that certain of these plans (which are definitely named in the specifications) shall be submitted to the Bureau for approval, while all others must be approved by the superintending constructor. Now the contract plans usually issued by the Government are only twelve or fifteen in number, but many hundreds of plans are actually needed in carrying on the work on each ship. All these plans are prepared by the contractors, and must be approved by the Government before they can be used in the yard.

In order that the superintending constructor may be able to act intelligently in the matter of passing judgment on these plans, his office is provided with a drafting room, in which there are employed a chief draftsman and such other draftsmen as the importance of the vessel and the number of vessels being built simultaneously will justify. Some of these are leadingmen, to each of whom is assigned a particular ship; the others are draftsmen of various grades, and to each of the more experienced of these is assigned some general subject, such as framing,

ventilation, drainage, ammunition handling, turret work, etc. When the contractors have completed a plan, they submit it to the superintending constructor, the plan being actually delivered to the constructor's chief draftsman. The latter, without examining the plan, assigns it to one of the draftsmen. This draftsman makes a careful detailed examination of the plan along the following lines: first, Is the plan in strict accordance with the contract plans and specifications? second, Is it in accordance with past practice? third, Is it a good plan? and fourth, Could it be improved? The draftsman's examination on the first of these points is based on the contract plans and specifications, copies of which are furnished him. It is his business to make a careful study of these plans and specifications, so that he may interpret properly what the exact requirements are. His investigation as to the second point is based on the corresponding plans of previous ships on file in the drafting room, the object being to determine whether the new arrangement is better or worse than has been previously used. The object of the third investigation is to make sure that if the plan is approved the work will prove satisfactory. This does not mean that it will necessarily be the best possible arrangement, but simply that it will work and that it will be strong enough. The last investigation is directed towards improvement in the plan, either by embodying practices that have developed since the Bureau's specifications and plans were made, or ideas that may have been suggested from other sources. The draftsman finally makes a memorandum of his criticisms of the plan, and submits the same to the proper leadingman. The latter goes over the plan with him and discusses with him the various points. The plan is finally turned in to the chief draftsman, with a written memorandum containing the criticisms of the plan and any suggestions as to its modification. The chief draftsman then makes a personal examination of the plan, more or less carefully and in detail, according to its nature and importance, basing such examination mainly on the memorandum referred to.

In case the modifications which he deems necessary are unimportant, or so clearly required as to admit of little discussion, he returns the plans to the contractors with a memorandum setting forth the changes desired. If, however, the changes are more important, he submits the plan to the constructor, with a verbal explanation of the points at issue. As a result of this discussion, he then sends the plan back to the contractors with a memorandum as to the changes desired. A copy of each memorandum is filed in the chief draftsman's office.

The plan having been returned to the contractors for revision, it remains with them either (*a*) to revise the plans as requested, (*b*) to induce the constructor to recede from his request or to accept some modification of the same, or (*c*) to appeal the case to the Bureau over the constructor's head. In unimportant matters the contractors usually yield without question; and this is also true in matters of more importance, but where the amount of money involved is not great. In larger matters the representative of the contractors has a verbal discussion with the constructor relative to the points at issue; and to this discussion is usually invited the chief draftsman, and, when the matter is complicated, also the leadingman and other draftsmen who have considered the plan in question. As the result of this discussion, the constructor either recedes from, or modifies, his request, or else he insists. In the latter case, the contractors have but two courses open, viz., either to change the plans accordingly, or to appeal to the Bureau. Which course they will follow depends mainly on the personality of the constructor.

The plan having been modified by the contractors, either according to the constructor's request, or to the Bureau's decision in case an appeal is made, is finally submitted to the constructor for approval. The latter then signs on the tracing a statement that the plan has been approved on a certain date for this particular ship, and then returns the tracing to the contractors; but before returning the tracing, he has made, in his own office, a blue print copy for his own file, as well as several additional copies for use in connection with the work of inspection.

The above procedure applies directly to plans which need be approved by the superintending constructor only. In case the plans must go to the Bureau for approval, practically the same course is followed before they are sent on to Washington, except that the superintending constructor does not insist on having changes made on the plans if the contractors object, but contents himself, when forwarding the plan, by stating to the Bureau exactly what demands he had made on the contractors which they had been unwilling to carry out. He also, at the same time, gives the Bureau his opinion of the plan, and recommends either that it be approved, that it be returned for revision, or that some other plan be made in lieu thereof.

The above procedure as to original plans applies in principle, also, to alterations made on plans that have already been approved. As the work proceeds, many changes in details are found necessary. These are usually first discussed between the representatives of the contractors and

of the naval constructor; and as a result of such discussion, the contractors formally re-submit the plan, showing on the same the alteration proposed, together with a note on the plan stating what the alteration is. When this alteration is approved by the constructor's signature in the alteration stamp on the plan, a new blue print is made for the drafting room file, or the alteration is formally entered on a print already on file.

The tracings having been finally approved and returned to the contractors, the latter make the necessary number of blue prints and issue them to the various yard departments. At the same time similar prints are issued from the constructor's office to his own representatives in charge of the outside work.

This outside work, *i. e.*, the work on the ships and in the shops, is usually in charge of the senior assistant constructor; and to assist him in the work he usually has one or two Carpenters and from three to six Special Mechanics. The Carpenters are warrant officers in the Navy, who have had experience on seagoing vessels and who are familiar with many details and conditions that might not be fully realized by men working continuously on shore. The Special Mechanics are, as the name implies, expert mechanics in their various lines, who act as sub-inspectors in matters of workmanship and other details. These men are appointed as a result of competitive examination. They are men of about the grade of foremen, and usually know thoroughly the details of the work for which they are employed.

The special mechanics usually attached to a superintending constructor's office are as follows: outside shipfitter, inside shipfitter or machinist, plumber, and shipwright. The outside shipfitter looks after the structural hull work in all its details; he also makes all tests for watertightness. The inside shipfitter looks after the installation of the turret and other guns, and all auxiliary machinery, except as to its electrical connections. The plumber looks after the drainage and flushing systems, the ventilation system, the galley, and other plumbing work. The shipwright looks after all the woodwork, including both deck and joiner work, and the painting.

The carpenters have direct charge over the special mechanics, and are themselves expected to look after matters of general arrangement, stowage, etc. In addition to these men, there is also employed an electrician, or, as he is called, an expert electrical aid, and it is his duty to look after all electric installations under the Bureau of Construction and Repair, and to make all tests of the same.

In actually carrying on the work, it has been found best to have the carpenters and special mechanics assemble every morning at a stated time in the office of the assistant constructor. At that meeting the carpenters and special mechanics bring to the attention of the assistant constructor any points which have come under their notice during the past twenty-four hours, while the latter, on the other hand, informs them of any decisions that have been reached, and gives them any other necessary instructions. The carpenters and special mechanics spend practically their entire time in the shops and on board the vessels, and the assistant constructor likewise spends much of his time in the same places.

I have so far described the manner in which the plans are examined and approved, and the means which are taken to ensure that the plans shall be followed in the construction of the ship. But in actually carrying out this scheme, a large amount of correspondence takes place, both with the Bureau and with the contractors; and to carry this on properly, there are provided a chief clerk, a file clerk, and a number of stenographers and typewriters. Owing to the fact that any question discussed or decided may at any time become important from a legal standpoint, it is necessary that proper and authentic copies of all correspondence shall be kept on file. To do this in connection with letters from the superintending constructor to the Bureau, in my own recent practice, such letters were written in quadruplicate; one copy went to the Bureau, one to the office file, one to the senior assistant constructor, and the other to the chief draftsman, the latter two copies being simply for their information and being subsequently destroyed. In the case of a letter written to the contractors, seven copies were made, four of which were sent to the contractors, and the other three distributed as before. The object in sending four copies to the contractors was to relieve them from the necessity of making copies for their individual files and other purposes. This was not a matter of regulation, but simply one of courtesy; and the same courtesy was extended by the contractors to me, in that, when they wrote me a letter, they furnished me with enough copies for my various files and other purposes.

The description of the work, above outlined, contemplates that the ship is built strictly in accordance with the contract plans and specifications. But while this is usually true of the main features of the ship, yet in many details changes are made, these being due sometimes to advances which have been made since the date of the contract, sometimes to change of policy on the part of the Navy Department, sometimes to

unsatisfactory reports that are received relative to the working of certain arrangements in actual service, and to many other reasons. Such a change is proposed by one of four parties, viz., the Bureau, the superintending constructor, one of the other inspectors, or the contractors; and the preliminary correspondence differs somewhat according to such origin. In its essential features, however, the correspondence agrees. The contractors submit a formal proposition in writing, either proposing the change and submitting their estimate of the amount whereby their compensation should be increased or decreased by reason of that change, or (if the change has not originated with them) simply submitting their estimate without any recommendation.

If the change pertains simply to the Bureau of Construction and Repair, the superintending constructor then makes his own estimate of the change in cost involved and forwards it, together with the contractors' estimate, to the Bureau, making at the same time such recommendation relative to the change as he may deem proper. If the change refers to work coming wholly, or in part, under the Bureau of Equipment or of Ordnance, the superintending constructor calls on the inspector of equipment or of ordnance for his estimate, and on receiving the same he includes it with the other papers to be sent to the Bureau. If the amount involved does not exceed $500, it is within the province of the bureaus to decide the question; but if the amount is larger than $500, the matter must be referred to the Secretary of the Navy. In either case, if the work is authorized, the Bureau so informs the constructor, and at the same time submits to the Board on Changes the question of the change in cost.

This board consists of three naval constructors; namely, a senior member, who is the same for all such boards at the various yards on the Atlantic coast; a second member, who is usually the senior assistant at the yard in question; and a third member, who is detailed for that duty from some near navy yard or private yard. This board meets at stated times in the office of the superintending constructor and considers the various changes that have been referred to it since the last meeting. When these changes refer to the Bureau of Construction and Repair only, the board of three naval constructors takes necessary action; but when any change comes wholly, or in part, under the cognizance of the Bureau of Equipment or of Ordnance, the inspector of such bureau is also a member of the board for that change.

A few days before the proposed meeting of the Board on Changes,

the senior member notifies the contractors, the constructor, and the other inspectors of the date of such meeting, and at the same time sends them a list of the changes which it is proposed to consider at that meeting. On the day of the meeting, as soon as the board has convened, the senior member obtains from a representative of the contractors a list of any changes on which the contractors desire to offer further argument; and when such changes are reached, the representative of the contractors appears before the board for that purpose. The superintending constructor is never a member of the board, but is called on by the board for any additional information the board may desire. The board, after further discussion, then votes on the amount of increased or decreased compensation, and submits a report relative to the matter to the Bureau of Construction and Repair. When that report has been approved by the Bureau in case the change in cost is less than $500, or by the Department in case the change is greater than $500, the case is settled and the legal right of the contractors to additional compensation in the amount specified, or, *vice versa*, the legal right of the Government to deduct the amount specified, is established.

Assuming that the work of building the ship is now regularly going on, it becomes necessary to consider the manner in which the contractors are paid for executing their contract. The contract provides that the contract price shall be divided into a certain definite number of equal parts (formerly usually thirty, but now usually fifty), and that the contractors shall be paid these equal installments as fast as they earn them, the fact of each installment having been earned being established by the joint certificate of the superintending constructor and the inspector of machinery to that effect. This certificate, so far as the superintending constructor is concerned, is based on figures and computations which, while not exact, are yet fairly close to the truth. Soon after the contract is signed, the contract price is, by mutual agreement between the Government and the contractors, divided into two parts: one part the machinery price, representing the portion of the work under Steam Engineering, and the other the hull price, representing the combined work under Construction and Repair, Equipment, and Ordnance. The hull price is again subdivided into about thirty items, such as drawings, structural steel, launching expenses, joiner work, handling armor, installation of battery, drainage, ventilation, anchor handling apparatus, painting, trial trip, etc., the portion of the hull price assigned to each of these items being based on past experience.

Now, from the calculations made during the designing of the ship, it is known approximately what the total weight under each of these items is; and by dividing the *lump sum* appropriated to each item by the corresponding *total weight,* we arrive at the *average cost per pound* under that item. Now, manifestly, the *actual* cost of any particular pound of such an item as ventilation varies very greatly according as we are considering, for instance, a pound of *sheet iron pipe,* or a pound of *electric motor.* Hence any system of estimating cost based on such weight units is of course liable to great error when applied to *individual separate* portions of the various items; but when that system is applied to the *weight totals* under the various items, the main result is *sufficiently close to the truth* for our purposes. In connection with the building of the vessel, an accurate record of all weights is kept; not the *estimated* weights, but the *actual* weight of every piece of material as it goes on the ship. These weights are entered in elaborate schedules, and many precautions are taken to see that nothing is omitted and that nothing is duplicated. These records are kept up continuously from the time the work on the ship is begun until she is completed; and while they are intended mainly to be used in connection with future designs, they are used during the progress of work in the computation of the amount of money earned by the contractors. This is done by ascertaining the actual weight completed under each of the thirty items above referred to, and multiplying each such weight by the average cost per pound of that item. This will give the amount of money earned by the contractors under each item; and by adding these amounts together we get the total amount earned.

In actually figuring up this amount, there are other refinements introduced. Certain amounts are deducted for work which has been weighed and placed in the ship, but which has not been entirely completed, such as, for instance, outside plating which has not been riveted up; and other amounts are added for work done in the shops which has not yet been weighed up. The cost of launching and the cost of trial trips are each put down as lump sums as these events occur; the cost of drawings is figured as a certain per cent. of several structural items.

When the grand total of the amount thus computed as having been earned under Construction and Repair, Equipment, and Ordnance, *plus* the amount which the inspector of machinery computes as having been earned under Steam Engineering, equals or exceeds one of the equal installments of the contract price, the superintending constructor and

inspector of machinery join in a certificate to that effect; and on the basis of that certificate, when approved by the respective bureaus and the Secretary of the Navy, the contractors are paid one of these equal installments. This scheme applies to all except the last three payments. These are not paid until after the ship has made a successful trial trip and has been preliminarily accepted; and even then there is still kept back a reserve of some thousands of dollars, held up to cover unforeseen contingencies and breakdowns. All this applies to the regular installments of the contract price; but there are other payments—those for authorized changes. Where these involve increases in compensation, the amounts determined by the Board on Changes are paid to the contractors on the certificate of the constructor that the work has been done. Where they involve decreases in compensation, the amounts are deducted from the final reservation.

As the work on the ship proceeds, it is subjected to continuous observation and inspection, and to tests designed to demonstrate its quality. In the early stages of the work, care is taken that frames and bulkheads are properly located, that the seams of plating come together properly, that rivet holes are fair, and that the riveting is properly done. As soon as the condition of the work warrants it, testing for water-tightness is begun. This is done by actually filling each compartment with water under a definite pressure, the head of water being obtained by means of a pipe screwed into the compartment and extending the proper distance above the base line. This testing is carefully done, and the seams and joints are gone over until the work is practically tight. As the work proceeds and auxiliary machinery is installed, more elaborate tests are made. Without going into details, it is to be noted that tests, representing the condition of actual service as nearly as possible, are made on the steering gear, turret operating gear, ammunition hoists, anchor handling gear, boat cranes, ventilation system, flushing system, drainage system, in fact, on all the items which enter into the efficient working of the ship. These tests are all made in accordance with a memorandum which the superintending constructor furnishes to the contractors as soon as practicable after work on the ship has begun, this memorandum being based on the specifications and any special instructions of the Bureau, as well as on past experience and practice.

By the time all this testing is well along, the ship itself is nearing completion. It is to the advantage of the contractors to run the official trial at as early a date as possible, and hence they usually apply for per-

mission to run this trial as soon as the machinery has had a successful dock trial and the work on the hull has proceeded far enough to warrant them in believing that permission will be granted. The contract requires that this trial shall not be run until the ship is completed and ready for delivery. This contract requirement, however, is never literally carried out, but is construed to mean that the ship is practically ready in all essentials and that the uncompleted work is either (*a*) unimportant, (*b*) work which cannot be done because of delays in delivery of material by the Government, (*c*) work, such as final painting, which must necessarily be deferred until after the trial trip, or (*d*) work which for some reason it is to the interest of the Government to so defer. When the contractors make their application for the official trial, the superintending constructor and the inspector of machinery make a report, stating whether or not, in their opinion, the ship will be ready at the time specified; and in this report, as well as in many other matters relative to the final completion of the ship, the superintending constructor represents not only the Bureau of Construction and Repair, but also the Bureaus of Equipment and of Ordnance. Unless some unexpected objection develops, the department authorizes the trial to be held on that date, and makes the necessary arrangements in connection with the appointment of a board to witness and report on such trial.

Just before the trial, the ship is always placed in dry dock, for the purpose of cleaning and painting her bottom; and at this time it is customary for a member of the Trial Board to arrive at the contractors' works to inspect the ship's bottom. When such member does not come, this inspection is made by the superintending constructor and reported to the Trial Board. In the meantime the constructor is preparing a list of unfinished work, made out in as much detail as possible. This list is usually quite lengthy, though many of the items are unimportant; but as it forms the basis of the Trial Board's report relative to unfinished work, it is important that it be as nearly right as possible. I have been in the habit of making a *preliminary* copy of the list about ten days or two weeks before the trial, and furnishing the same to the contractors so as to enable them to make objection to any items if they see fit. By this course, any matters in controversy can usually be settled before the official list is made. Finally, the day before the ship is to leave on her trial, the list is brought up absolutely to date; and numerous copies of the now *official* list of unfinished work are made and furnished to the Trial Board, the contractors, and the other inspectors. The senior

assistant constructor usually goes on the trial as the representative of the superintending constructor, and carries with him one of the carpenters, certain special mechanics, one or two draftsmen, the electrician, a stenographer, and such other help as he may deem necessary.

While the trial is primarily to determine whether or not the ship fulfills the contract requirements as to speed, strength, stability, manœuvring qualities, etc., yet the Trial Board also reports at length on two other points, namely, (*a*) the unfinished work required by the contract and authorized changes, and (*b*) any changes and improvements which in the board's opinion are necessary or desirable.

As soon as the ship returns from her trial she is thoroughly cleaned, and work is immediately begun by the contractors towards finishing up the various items of work given in the official list of unfinished work. While this is going on, the report of the Trial Board is referred by the Department to the superintending constructor for comment; and on the basis of the latter's recommendations the Bureau and the Department come to a decision as to any changes to be made, or any other matters in dispute, the result of all this being definitely to establish and settle just what work must be done before the ship is delivered. As this work proceeds and draws near completion, the contractors inform the Department that they will be ready to deliver the ship on a certain day, and ask that it be duly received. Unless there be objection raised by the inspectors, this delivery is usually authorized on the date requested by the contractors.

Immediately previous to that date there are placed on board the ship all the various articles of equipage and supplies that have been delivered for her, and on that date she is towed to the navy yard specified in the contract. The commandant of the yard gives a receipt to the contractors for the ship, and takes charge of the ship as a whole; but the representatives of the contractors remain with the ship for some days, until all the miscellaneous portable articles are checked up by the representatives of the Government and of the contractors, when the contractors obtain a receipt for these also.

Soon after this the ship goes into commission; and this usually results in numerous complaints being made as to certain items of work, as well as numerous changes being suggested, by the officers of the vessel. All of these are referred to the superintending constructor for recommendation, and when he has finally submitted his report on these points he has finished with the ship so far as her construction is concerned. There still

remains the final financial adjustment, which is deferred until the constructor finally reports that all work has been completed except certain definitely specified items, which for some reason cannot be done and for which a certain amount should be deducted from the contract price. The above course is sometimes varied by putting the ship in commission at the works of the contractors.

To successfully fill the position of superintending constructor, several qualifications are necessary. In the first place, there is the extensive *knowledge of detail,* which is gained only by experience. It is, of course, to the contractors' interest to build as cheaply as possible, and thus all contractors are continuously endeavoring to modify details of construction in that direction. It is the constructor's business, on the other hand, to see that the details are entirely satisfactory. While this work is mainly accomplished through the medium of examination and criticism in the drafting room, yet the *personal* knowledge of detail possessed by the constructor is a very large factor in keeping down the number of plans submitted by the contractors for the mere purpose of cheapening the construction.

Another important quality is *quickness of decision.* In an establishment employing, as most of these private yards do, thousands of men, time is very valuable; and it is important that, when the contractors submit a proposition, they be given a prompt answer. In some cases the matter of time is so important that the contractors would really prefer an adverse decision given immediately rather than a favorable decision given at some later date.

Another essential quality is *firmness,* which, however, must not be carried to the limit of obstinacy. Having once announced his decision, the superintending constructor should not change it, except for *very good* cause. It greatly facilitates the work if it is thoroughly understood that when a matter has once been decided, it is to be regarded as settled.

Another important quality for a superintending constructor to cultivate is a *judicial temperament;* and in this particular there is a tendency among men, when first assuming duty at a private yard, to become possessed of the idea that the interests of the contractors and of the Government are diametrically opposed, and that any hardship they can inflict on the contractors results in a corresponding gain to the Government. It must not be forgotten that there are two sides to almost every question; and if the superintending constructor will approach disputed questions with the idea of ascertaining the truth, rather than with the

idea of upholding the Government side at any cost, he is much more likely to achieve success.

And lastly, one of the most important things is the cultivation of harmonious and pleasant *personal relations* between the constructor and the other inspectors and the representatives of the contracting firm. With such relations and a willingness to discuss disputed points on their merits, without introducing any personal element, it will be found that the work will progress more rapidly and more efficiently, to the greater advantage of the Government, and to the greater credit of the superintending constructor.

THE AIR OF THE NEW YORK SUBWAY PRIOR TO 1906

By GEORGE A. SOPER

Read November 22, 1906

CONTENTS

		Page
1.	Introduction	58–59
2.	Scope of the Investigation	59–61
3.	Essentials of Construction and Operation at the Time of the Investigation	61–69
4.	Temperature and Humidity	69–80
5.	Chemical Condition of the Air	81–93
6.	Bacterial Condition of the Air	93–104
7.	Odors	104–108
8.	Dust	108–116
9.	Final Conclusions	116–118

INTRODUCTION

The object of this paper is to record some hitherto unpublished facts concerning the quality of the air of the New York subway before any material change was made in its ventilating arrangements, and to seek to explain the essential conditions which controlled it.

The data were collected during an investigation of the subject, covering six months, which the Board of Rapid Transit Commissioners for the city of New York requested me to make in June, 1905.

The original data, largely in tabulated form, together with various reports, covering in all about one thousand pages of typewritten manuscript, have been in the possession of the board since February, 1906. Most of these data will probably never be printed.

Being assured that a fuller account of the methods and conclusions than had hitherto been published might be of service to engineers, I have, at the request of the Society of Arts, prepared the review of the investigation which constitutes the following paper. The Board of Rapid Transit Commissioners has courteously given its consent to this use of the facts.

ACKNOWLEDGMENT OF ASSISTANCE

It was through the intelligent and skillful efforts of the persons who were called upon to aid in the investigation that the results were in large part due.

The average number of assistants continuously engaged on the work was ten. From first to last, there were twenty-one persons officially connected with the investigation; about two-thirds of this number were technical school graduates.

Especially capable work was done by Floyd J. Metzger, Ph.D., in the chemical analyses; by Clinton B. Knapp, M.D., and Payn B. Parsons, M.D., in the bacteriological studies; and by George S. Frost, C.E., in the meteorological observations. Aid of an unusually competent character was given in the studies of ventilation and in compiling the data by Mr. John P. Fox.

Valuable counsel and other assistance was given by a number of the author's friends who were not officially connected with the investigation. Most of these were professors in Columbia University. Among them may be mentioned Dr. Charles F. Chandler, Professor of Chemistry; Dr. T. Mitchell Prudden, Professor of Pathology; Dr. William Hallock, Professor of Physics; and Dr. Philip Hanson Hiss, Professor of Bacteriology. To these and others whose help added accuracy and value to the investigation, I desire to express here my sense of appreciation and thanks.

SCOPE OF THE INVESTIGATION

The principal questions investigated related to temperature, humidity, odor, bacteria, and dust. The conditions found in the subway were compared with the conditions found in the streets through which the subway runs, and occasionally with conditions in other places.

In studying each subject, my plan was to obtain an accurate knowledge of: First, the conditions which existed; second, the causes of these conditions; and third, what, if any, remedy was required.

In seeking to explain the causes of the conditions, it was necessary to take account of the sanitary care which the subway received from the company which operated it and the manner in which ventilation was accomplished.

In two of my official reports, the only ones printed, and in a paper

read before the New York Academy of Medicine, March 15, 1906, the character of the sanitary supervision was described and specific recommendations made for improving it. Little will be said here concerning this matter. Inasmuch as the way in which the subway was ventilated has never been fully described, a brief description of it will be given.

No attempt was made to devise a comprehensive system of ventilation or cooling to improve the air. Experiments in this direction were being made by the regular engineering staff of the commission. I merely studied the effects of these experiments and reported upon them.

My single expression of opinion with regard to cooling the subway was that substantial benefit would result if more and larger openings were made between the subway and the outside air, and that improvements to the cars might prevent the production of the excessive amount of heat through a more economical employment of the power. The first of these suggestions was made early in the investigation. Its correctness has since been fully demonstrated.

In all, there were about 2,200 chemical analyses of air, 3,000 determinations of bacteria, and about 400 other analyses in special studies of dusts, oils, disinfectants, and other substances. About 50,000 separate determinations of temperature and humidity were made prior to the adoption of a system for automatically and continuously recording temperatures throughout the length of the subway and in the streets.

The methods employed in studying the different topics were, for the most part, such as had been used in other sanitary and meteorological investigations in which a considerable degree of accuracy was required. It is not claimed that they would have been the best to adopt in a purely scientific research. It was necessary to design them for practical as well as accurate use.

For the most part, the air to be analyzed was collected at an elevation of 18 inches to 2 feet above the pavement. This height was decided on as the most convenient and suitable, after an attempt had been made to collect it at the breathing line. Only by taking samples near the ground was it possible to avoid attracting curious crowds of persons whose presence would have rendered the samples valueless. Tests made of air from different elevations indicated that no substantial error was made in taking samples near the pavement.

Very few samples of air were taken in the cars. Persons familiar with the conditions of crowding in the cars of the New York subway at practically all hours of the day will appreciate the inconvenience with

which delicate and bulky scientific apparatus could be used among persons standing as close together as it was physically possible to stand. Furthermore, the question at issue was not whether the passengers in the cars obtained good air or not, but whether the air outside the cars was satisfactory.

ESSENTIALS OF CONSTRUCTION AND OPERATION AT THE TIME OF THE INVESTIGATION

The details of construction and equipment of the New York subway have been made the subject of so many extended and authoritative accounts that it is unnecessary to deal exhaustively with these matters here. It seems desirable, however, for the sake of clearness, to refer briefly to some of the features of construction and operation which bore directly upon the condition of the air at the time of the investigation.

Part of Subway in Operation

The part of the road which was in operation during the period of this investigation extended from the lower end of Manhattan Island northward to 96th Street and Broadway, where it divided, one branch continuing along Broadway to 157th Street, and the other eastward and northward until it crossed under the Harlem River and reached that part of the city known as the Bronx.

Nearly all of this road was underground. There was a short, exposed portion of a few blocks covering a valley at 125th Street, and the branch to the Bronx, after crossing the Harlem, soon emerged upon an elevated structure, which it did not leave to the end of the line; but the parts of the subway which were not underground were not considered in this investigation.

Section Chosen for Closest Observation

The length of the road, about 21 miles, and the rather wide variety of conditions which occurred in it made it desirable to confine the investigation as far as practicable to a representative section.

There was no difficulty in selecting this section. The road between 96th Street and the Brooklyn Bridge was, in every respect, the most important. Further on in this paper it will be shown that this section was divisible into two parts, distinct differences both as to details of

construction and the condition of the air being noticeable between the part north of 59th Street and that south.

Nearly all the studies recorded in this paper, except those of temperature and humidity, refer especially to the representative section between 96th Street and the bridge. In many cases, however, they have a much wider application.

The length of the section was about 6 miles. The cubic air space included was, in round figures, 26,100,000 cubic feet, including the stations.

The section was four tracks wide, excepting a piece of tunnel which ran between 42d Street and 34th Street. Here there were two tunnels of two tracks each, running side by side, cut through the rock.

Sanitary Features of Construction

By the contract we learn that it was intended, when the road was designed, that it should be easily accessible, light, dry, clean, and well ventilated.

It was partly to accomplish these ends that the road was built as close to the surface of the streets as physical conditions permitted.

Dryness.—Much care was taken to make the subway dry. It was declared to be the "very essence of the specifications" for construction to secure a structure which should be entirely free from the inward percolation of ground or outside water.

To accomplish this end, a practically continuous sheet of asphalt was built within the concrete bottom, sides, and top of the structure. This water-tight envelope consisted of from two to six thicknesses of asbestos, or other similar felt, laid in hot, natural asphalt. In addition, every part of the road was so drained that water finding access thereto was led away by natural drainage or automatic pumps to the city sewers.

Lighting.—The roof of the subway was so close to the level of the streets that it was possible for the builders to make extensive use of vault lights for illuminating the stations with natural light. Full advantage was taken of the possibilities in this direction. The lights were made of cast-iron frames, with lenses about 2½ inches in diameter of strong glass set in cement. The area of the vault lights at some stations was so great that little artificial light was employed, excepting at night.

Incandescent lamps were the only artificial lights used except for signals.

Provisions for Cleanliness.—In constructing the road, provisions for keeping the subway clean were carefully carried out at the stations. The platforms were made of cement and the walls of tile, the joints and moldings being such as to permit of easy cleaning. The stairways were supplied with safety treads, which collected much street dirt, thus keeping it from entering the subway.

Provision was made in the original design for a concrete roadbed,

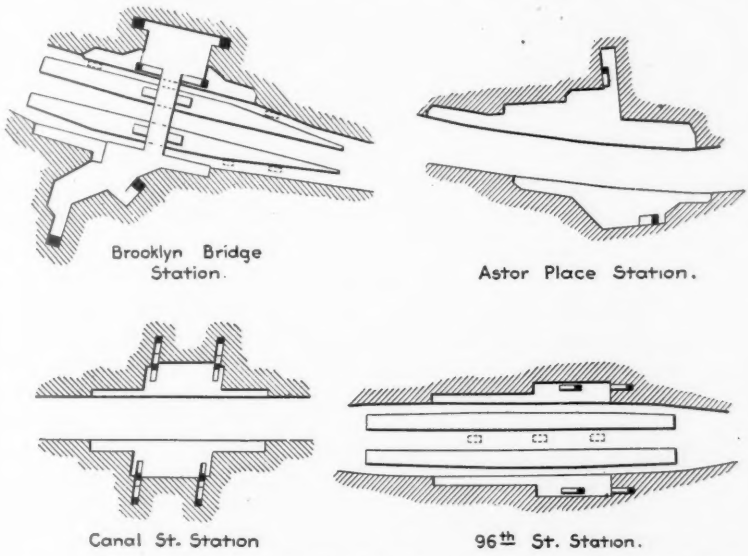

FIG. 1.—PLANS OF FOUR TYPES OF SUBWAY STATIONS SHOWING THE STAIRWAY OPENINGS TO THE STREET

which would have enabled the road to be kept clean between stations; but modifications in the contract, after it was let, resulted in the construction of a broken stone roadbed, from which only comparatively large particles of refuse could be removed.

Stations.—There were twenty stations on the section chosen for especially careful study. Most of them were situated outside of the railway, the two sides being duplicates.

With few exceptions, each side was equipped with two water-closets for the use of women and men, respectively. They were well furnished with bowls, hand basins, and sinks, each of which was supplied with a back-aired trap and connected with the sewer.

The closets were designed to be ventilated through ducts connected with the street above, and, toward the close of this investigation, electric exhaust fans were set in many of the ducts to force the air of the closets into the street. At the beginning of this investigation, ventilation was effected only through the doors communicating with the subway.

The express stations, of which there were five in the section especially studied, were larger than the local stations, and provided with platforms between the tracks. The express stations were about 1½ miles apart. They were: Brooklyn Bridge, 14th Street, 42d Street, 72d Street, and 96th Street. The plans of four types of subway stations showing the stairway openings to the street are shown in Figure 1.

Track.—The track consisted of the standard gauge roadway, with the wooden cross-ties and broken stone ballast, which is commonly seen on the best steam railroads out of doors. This type was adopted at the request of the operating company, after the general contract for the road had been let.

The original contract had specified that in the underground portions of the railway the tracks should consist of rails laid on a continuous bearing of wooden blocks, the grain of which was to be transverse to the length of the rail. The blocks were to be held in place by guard rails secured to metal cross-ties imbedded in the concrete floor.

Provisions for Ventilation

The subway was ventilated through the stairways at the stations and through blow holes in the roof.

Blowholes.—All of the blowholes which were originally built were located in that portion of the road which lay above 60th Street. They were rectangular in shape, and opened upon small grass plots which occupied the center of the wide boulevard known as Upper Broadway. Iron railings surrounded the openings. To prevent the entrance of large objects, the openings were covered with coarse wire netting.

The blowholes were located above the center of the railway, one being situated a little beyond each end of each station. An additional blowhole was placed midway between each two stations above 59th Street. The total number of blowholes between 59th and 96th Streets was eighteen. Each was about 7 x 14½ feet in the clear. Wire nettings, beams, and other objects took up about one-quarter, or more, of this space.

Stairways.—The stairways between the streets and the stations varied somewhat as to width and direction. Below 59th Street they were usually placed at right angles to the line of the road; above 59th Street they were parallel to the road. There were usually two stairways, each in cross section about 5½ x 7½ feet, to each local station above 59th Street, and eight narrower ones to the other local stations.

The stairways were covered with ornamental kiosks, which stood upon the sidewalks near the curbs. They were without doors. The

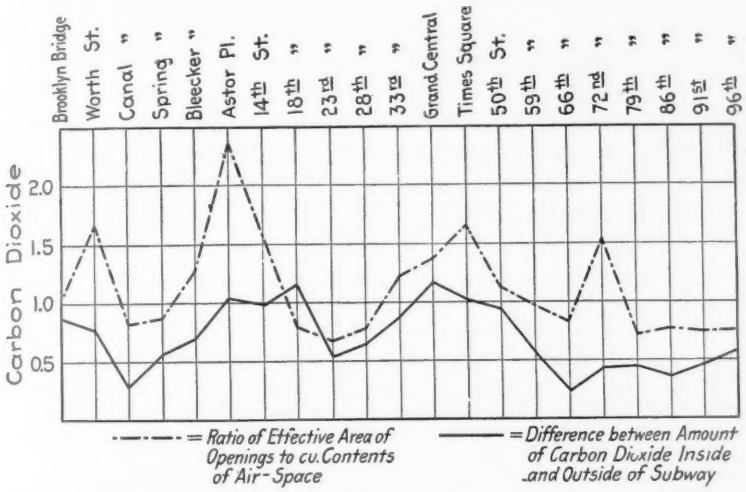

FIG. 2.—RELATION BETWEEN THE CHEMICAL CONDITION OF THE AIR IN THE SUBWAY AND THE RATIO OF THE EFFECTIVE AREA OF THE OPENINGS TO THE CUBIC CONTENTS OF THE AIR SPACE AT DIFFERENT STATIONS

kiosks opened north and south above 59th Street; below 59th Street they usually faced east and west.

The relation between the chemical condition of the air in the subway and the ratio of the effective area of the openings to the cubic contents of the air space at different stations is shown in Figure 2.

PHENOMENA OF VENTILATION

Exchanges of air between the subway and streets took place chiefly by reason of the movement of trains.

Effects of Train Movements.—The subway was about 50 feet wide

and 18 feet high on the four-track section between Brooklyn Bridge and 96th Street, and the cross section of a car occupied about 14 per cent. of this subway section. The trains were from 150 feet to 408 feet long.

The number of passengers in the cars varied somewhat at different hours of the day, but the cars were usually crowded. There were fifty-two seats in each car, and when the aisles and platforms were filled the total number of passengers per car ranged from about 115 to 140. The densest crowding occurred in the rush hours and throughout the length of that portion of the subway which was under closest observation.

The number of cars per train, the number of trains per hour, and the speed varied at different hours. The local trains usually consisted of five cars, and ran at a rate, exclusive of stops, of about 21 miles per hour. The express trains generally consisted of eight cars, and ran at a rate, exclusive of stops, of about 26 miles per hour.

The total number of passengers carried in the subway, as indicated by an official statement of the ticket sales, averaged, for the last two months of 1905, 440,000 per day. There were about twice as many passengers carried in November and December as in July (see Table I).

TABLE I

SHOWING THE NUMBER OF PASSENGERS CARRIED FROM EACH STATION OF THE SUBWAY FROM JULY TO DECEMBER, 1905, INCLUSIVE

(From the report of the Board of Rapid Transit Commissioners for 1905.)

	Number of passengers.
July	6,076,241
August	7,085,814
September	8,843,314
October	11,329,216
November	12,677,761
December	13,715,946

As a train moved through the subway, air was forced ahead of it and air followed it. As a rule, a general current flowed along the track on each side of the subway in the direction of the train movement, and these currents continued even when no train was within hearing distance. The important action of a train was to force air along with it, but where stairways or blowholes occurred and offered lines of diminished resistance, the air rushed out through them as a train approached and rushed in as the train went by.

The difference in barometric pressure necessary to set up these air currents was exceedingly slight; the effect of friction against the walls and pillars of the subway and the sides of the stairways considerable. A great part of the force with which the air currents were set in motion was generally used up in eddies about the trains.

The movement of the air depended upon the speed of the nearest train, the movement of other trains in the vicinity, the size and location of the neighboring openings to the outside air, the size of the particular cross section of the subway with reference to the sections of the moving trains, the force and direction of the wind in the streets with reference to the position of the stairways, the difference in temperature inside and outside of the subway, and other conditions.

The chemical analyses of air which were made gave data from which the frequency with which the air was renewed could have been computed had the number of passengers present at any corresponding time and part of the subway been known. Accurate information on this subject was not, however, available.

TABLE II

RESULTS OF COLOGNE EXPERIMENTS, SHOWING RATE OF PASSAGE OF AIR FROM STATION TO STATION

POINTS OF OBSERVATION.	DISTANCE TRAVELED.	TIME CONSUMED.	SPEED.
Stations.	Feet.	Minutes and seconds.	Miles per hour.
Worth Street to Brooklyn Bridge	835	5:25	1.75
Worth Street to Canal Street	910	1:15	8.27
Worth Street to Canal Street	910	7:35	1.36
Spring Street to Canal Street	1,540	5:30	3.18
Spring Street to Canal Street	1,795	10:10	2.00
Spring Street to Canal Street	1,795	12:20	1.66
Spring Street to Bleecker Street	1,230	3:40	3.81
Spring Street to Bleecker Street	1,230	5:25	2.58
Average	. .	. .	3.08

Anemometer Observations.—Observations with anemometers were made at a number of stations on several occasions. As a result of seventy-nine of these observations, covering, in the aggregate, two hours and thirty-five minutes, made at eight stations, it was calculated that an average of 573,000 cubic feet of air had moved in and out of one

stairway per hour. This was at the rate of 9,500 cubic feet per minute.

The maximum movement of air observed was when 63,000 cubic feet passed in at one station in one minute through a single stairway. The velocity of the current on this occasion was 16⅓ miles per hour.

Circulation of Air between Stations.—That the air circulated freely from one station to another was shown by CO_2 analyses (to be referred to later) and by noting the time that it took an odor to pass from one station to another. Cologne of a highly concentrated grade, and in sufficient quantity to produce a distinct perfume throughout the air of a station, was used at several points and the odor noted up and down the line with the help of assistants with stop watches. Care was used that the cologne should not be transported mechanically by coming in contact with the trains in liquid form. The results of the cologne experiments are given in Table II, and of CO_2 analyses in Table IV.

As a result of eight cologne experiments, it was found that the odor was carried from station to station at the average rate of 271 feet per minute, or about 3.08 miles per hour. The cologne vaporizer used in these experiments is shown in Figure 3.

Ventilation of the Subway and Human Lungs Compared.—The ventilation of the subway bears an interesting resemblance to the ventilation of the human lungs, and it will help to understand the former if we trace some of the details of this analogy.

The ventilation of both the subway and the lungs is due to currents of air passing inward and outward as a result of changes of pressure, caused chiefly by the expansion and contraction of the enclosed space.

It is true that with the lungs the size of the enclosed space is alternately enlarged and reduced through the movement of its walls, while in the subway the size of the enclosure is increased and diminished through what is termed the piston action of the trains; but in other respects the similarity is close.

In the normal amount of air which passes out of the subway on the approach of a local train, and is replaced by an indraught of fresh air as the train draws away, we have what physiologists, in speaking of the ventilation of the lungs, call the "tidal air." In the additional quantity which is drawn in by the express trains, we have the "complimental air," and in the excess which is forced out by express trains the "reserve or supplemental air."

These three, the tidal, complimental, and supplemental, we may term the "respiratory or ventilating capacity" of the subway.

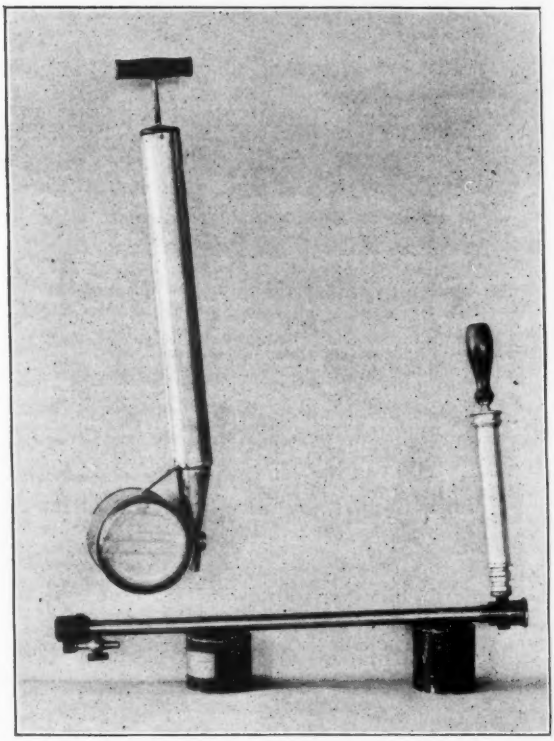

FIG. 3. — THE KONISCOPE (BELOW) AND THE COLOGNE VAPORIZER (ABOVE)

Finally, there is an amount of air which remains in the subway and is not immediately forced into the streets by any combination of local and express trains; this we may call the "residual air."

This terminology is appropriate and convenient for general purposes, and it is suggested that it should come into use among ventilating and sanitary experts in dealing with ventilation problems of much less strictly physiological character than those to which it has hitherto been confined.

TEMPERATURE AND HUMIDITY

From an early period in the construction of the road, an effort had been made to observe the temperature and humidity at a number of points by means of automatic, recording thermometers. Later, when

the sanitary conditions were being made the subject of investigation, these records were critically examined and the observations put upon a more exact basis.

In this section we will briefly review the early and later methods and the final system of observing temperatures, and then pass to a consideration of the results of all observations.

Methods Employed

The various methods employed may be conveniently considered separately.

Early Methods.—The earliest date upon which any systematic record of temperature or humidity was made in the subway was June 26, 1903. At that time a number of maximum and minimum thermometers and stationary wet and dry bulb hygrometers, with some small Richard thermographs, were placed in the subway at various places between the City Hall and Columbus Circle stations, at different points on the line above 50th Street, and outside.

The accuracy of the observations made with these instruments was carefully studied by me in July, 1905, with the result that the temperature records were found to be generally accurate, probably to within 5°, and the humidity observations to within 20 per cent. The readings were all generally too high.

Methods Used from July 1 to September 18, 1905.—After the work of observing temperatures and humidities came under my direction, no maximum and minimum thermometers nor stationary wet and dry bulb hygrometers were employed.

Temperature and humidity observations were first undertaken in this investigation on July 1, 1905. They were made with sling psychrometers designed as made for the United States Weather Bureau, with some minor changes intended to fit them especially for subway work.

The psychrometers consisted of two mercurial thermometers 24 cm. long, graduated from —10 to 125° F., fastened upon an aluminum back, 1½ cm. apart, centre to centre.

The bulbs projected beyond the aluminum back for about 5 cm., one of the bulbs being covered with cotton cloth. The upper end of the aluminum back was connected by two loose wire links, fitted by a pivot to a substantial handle around which the thermometers could be whirled.

To make it conveniently transportable, the whole instrument was fitted into a specially designed cylindrical aluminum case, and was there secured by a bayonet lock at the top. The case was arranged so as to hang from a leather strap, so that the instrument might be slung over the shoulder when not in use. The psychrometers were made by Schneider Brothers, 265 Green Street, New York.

The manner in which the sling psychrometer was employed and the tables used to calculate the humidity are contained in W. B. No. 235, issued by the Weather Bureau of the United States Department of Agriculture.

When tested at a testing station, established for the purpose of determining the accuracy of the various instruments employed in the investigation, the thermometers were found to be accurate to within one-tenth of 1° F.

Four observers were regularly employed in making the psychrometer observations. Each visited a given number of stations per day, between 9 A.M. and 5 P.M., and recorded the temperature and humidity inside and outside of the subway. The express stations were visited twice.

In making an observation at a station, the observer took into account the air throughout the entire length of the platform. It was usual to make five observations at about equal distances from one end of a platform to the other. Each observation consisted of at least four readings of the thermometers. The readings were recorded in notebooks to the nearest half degree.

At first sight it may appear that these data, obtained at only certain hours of the day, with the late afternoon and early morning left out, may give a misleading idea of the average temperatures for the twenty-four hours. This, however, is not the fact. Continuous observations carried on day and night for a week showed that the data so obtained, when worked into averages for days and weeks, gave an excellent knowledge of the conditions.

The total number of temperature and humidity observations to November 16 was about 50,000, considering the temperature and humidity observations separately.

Final System of Observing Temperatures.—The observations with sling psychrometers were not intended to furnish the data from which the most important deductions concerning the temperature were to be derived. The instruments selected for this purpose were thermographs.

The suitability of practically every well-known thermograph on the market was considered for this use. Specimens of five makes were set

up in the testing station and compared for several weeks before a choice was finally made.

The instruments chosen were the largest thermographs made by J. Richard, Paris. About one dozen of these were especially imported for subway use; others were obtained in America. The total number of thermographs which were put in use was twenty. On test they were found to be capable, under the practical conditions required, of recording changes of temperature to within one degree and time to within ten minutes, if visited daily and kept clean and adjusted.

As may be supposed, the thermographs never showed the changes of temperature which actually occurred. They were most accurate when the changes were slow and not very decided. To be precise, the thermograph curves could be interpreted as neither more nor less than the record of the net effect of several conditions, only the leading one of which was the temperature of the subway near the instrument.

Observations with a delicate mercurial thermometer showed that changes of temperature occurred in the subway of far greater extent and frequency than were indicated by the thermographs (see Fig. 4). But if they did not give a scientifically perfect record of every change of temperature, they were none the less serviceable. It was not desired to know each change, but only the more decided and lasting ones.

A special observer was trained to keep the thermographs in good condition, to check their readings with an accurate mercurial thermometer, to make necessary adjustments, to wind the clocks, and to renew the record sheets every week. The records were systematically filed.

The management of the thermographs and the observations of relative humidity were turned over to the engineering corps of the board on November 18, with the recommendation that the system be made permanent.

The thermographs were placed in specially constructed cages in the stations of the subway, generally at the end of the platform which was approached by incoming trains. They were as far removed as possible from local draughts, and about 4 feet above the pavement.

The thermographs located out of doors were placed in cages of similar construction to those used underground. The locations of the outside thermographs were selected with a view to having the instruments in the shade, remote from the effects of radiation from pavements and buildings, and beyond the influence of outrushing currents of air from the subway.

The records obtained from the thermographs gave an excellent idea

of the average differences in temperature which existed between the subway and streets and between one subway station and another. They also showed fluctuations in temperature which gave clews to the origin of the heat, to the extent and ways in which ventilation took place, to the movements of trains, and many other instructive matters.

Throughout the period of this investigation, observations of temper-

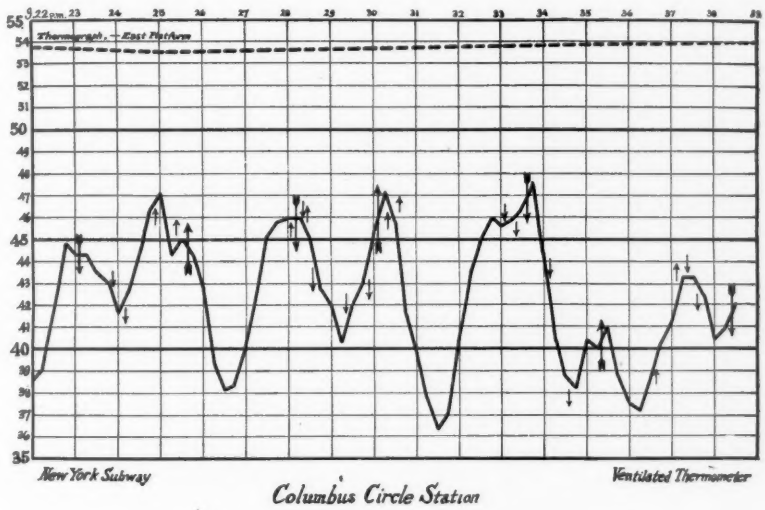

FIG. 4.—RAPID VARIATION IN TEMPERATURE NOTED, WITH A VENTILATED THERMOMETER, AND ACCOMPANYING TRAIN MOVEMENT. THE SMALL ARROWS SHOW THE MOVEMENT OF LOCAL, THE LARGE OF EXPRESS, TRAINS IN EACH DIRECTION

ature were made by the company which operates the subway. These observations consisted of hourly readings of ordinary tin-backed thermometers inside and outside of the stations. The thermometers were usually read by colored porters, few of whom were competent to do this work properly. None of these records is used in this paper.

RESULTS OF TEMPERATURE AND HUMIDITY OBSERVATIONS

Before the Subway Was Opened for Travel.—In view of the overheating of the subway which took place in 1905, it is interesting to

review some of the temperature characteristics of the road before it was thrown open to travel. In reviewing these figures, it must be remembered that the entrances, exits, and blowholes were more or less closed at this time, and that a free circulation of air in and out was correspondingly obstructed. Had all the openings been free, there would have been less difference between the inside and outside air.

During construction, and before the subway was covered by a roof, its temperature was practically that of the outside air.

After the roof was put on, marked differences occurred. The temperature of the subway was now much more constant than that outside.

Before trains were run, hourly and daily changes of temperature in the streets seemed to affect the subway but little. The more marked and continued changes, however, produced visible effects.

In winter the air outside was cooler, and in summer warmer, than the air of the subway. The total range of temperature of the subway air at 112th Street for the year August 6, 1903, to July 27, 1904, was from 22° to 68°, or 46°; while the range outside was from 2° to 94°, or 92°. In other words, the range of temperature in the streets was twice as great as the range in the subway.

During the hottest week in the subway, before it was opened, the temperature, according to the 112th Street records, averaged 59.4°, while the street temperature was 77.7°. At its hottest, the subway was 18.3° cooler than the streets.

The records of early temperatures in the subway give no idea of the normal temperature of the earth through which the subway runs. The temperature probably varies according to the depth under the surface, the presence or absence of ground water, the nature of the rock or earth, and other conditions. In the deep tunnel which runs under Central Park, a temperature of 54° was frequently observed in June and July, 1903, although the temperature outside at the same time occasionally reached 95°.

In the year in which the road was opened for travel, the subway at Columbus Circle (59th Street) averaged about 53° warmer than the average temperature in the streets.

In March and April the average temperatures inside and out were practically the same.

From the middle of April to the end of September, the subway at Columbus Circle was cooler than the streets.

Immediately after Opening the Subway to Travel.—From the middle of August until the opening day, October 27, 1904, the subway was gradually cooling from the highest point which it had reached in the summer. From that time to the end of the year the temperature gradually fell.

The large amount of travel which the subway experienced at the start did not visibly affect the decline of temperature which was to be expected at this season of the year.

For the first ten weeks of 1905, the subway was slightly warmer than in 1904. It is not clear that this difference was due solely to the fact that the road was in operation. The temperature out of doors was warmer than it had been the year before.

Beginning about the middle of March, or at that season when, in other years, the temperature inside and outside had been about the same, the heating due to the operation of the road first became distinctly visible. Instead of the streets becoming warmer than the subway, as had been the case the year before, the temperature inside rose also. Thenceforth a higher temperature in the subway became the rule, both winter and summer.

The Summer of 1905.—Throughout the investigation with which this paper is concerned, the subway was generally warmer than the streets. The only exceptions were when the outside temperature rose rapidly after a prolonged low period. This usually occurred in summer in the middle of the day, and in winter after a cold snap.

The excess of subway temperature over outside temperature increased considerably during the autumn and winter months. In the early part of July the difference between the temperature for the whole day inside and outside of the subway was less than 5°. In the latter part of September it was over 10°. In January, it was at some stations about 20°. An average daily difference, for a week, of 30° was found at one station.

Referring now to the observations of temperature made with the dry bulb thermometers of the sling psychrometers, we are prepared to obtain a better idea of the conditions which obtained in the summer after the subway was opened.

The subway grew warmer as the summer advanced. It averaged 81° through July, 1905. In the week of August 4 to 10, it was 83.4°. Thereafter it declined very gradually, until the latter part of September, when it was 76°.

In the week of September 29 to October 5, there was a slight rise to

78°, corresponding with a rise of temperature out of doors. This was followed by a more rapid decline than had occurred at any time before. Uncomfortably high temperatures were not again experienced in 1905.

During its hottest period the temperature of the subway followed the temperature of the outside air, except in the more extreme and rapid changes of the latter. This correspondence is seen to be most marked when the data for inside and outside are compared in the form of weekly and monthly averages (see Table III and Fig. 5).

The temperature in the subway for the daytime for July and August,

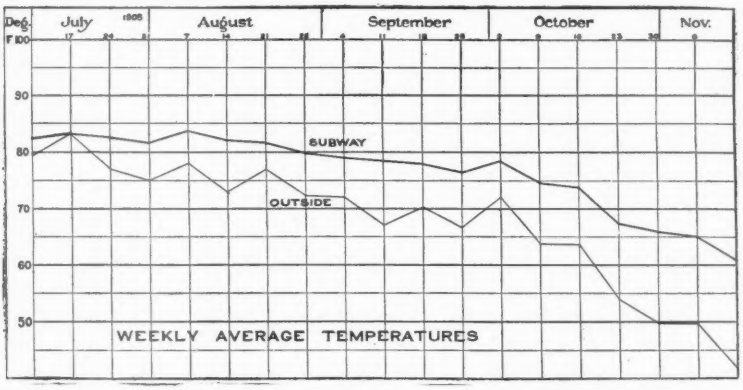

FIG. 5.—WEEKLY AVERAGE TEMPERATURES IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905. THESE AVERAGES ARE MADE UP OF 47,476 OBSERVATIONS

combining the records of these two months to form an average, was 82.4°; it was 76.8° outside; difference, 5.6°.

Highest Temperatures in the Summer of 1905.—The highest temperature observed in the subway during the investigation was 95°. This occurred at the Brooklyn Bridge station, July 18, 1905, at 3.50 P.M.

The hottest week was that of August 4 to 10, inclusive. The average daily temperature for the subway during this time was 83.4°; for the outside air, 78.2°; difference, 5.2°.

The maximum temperature observed in the subway during this hottest week was 88.2°; in the streets it was 88.2° at the same time.

The Warmest and Coolest Stations.—The coolest station was Canal Street, and the warmest Astor Place.

TABLE III

WEEKLY AVERAGE, MAXIMUM AND MINIMUM TEMPERATURE, AND RELATIVE HUMIDITY IN THE SUBWAY AND STREETS AS DETERMINED BY SLING PSYCHRÓMETER OBSERVATIONS FROM JULY 1 TO NOVEMBER 16, 1905. THE NUMBER OF OBSERVATIONS INCLUDED IN THIS TABLE IS 97,168

Date, 1905.	Place.	Average		Maximum		Minimum	
		Temperature.	Humidity.	Temperature.	Humidity.	Temperature.	Humidity.
July 1–13	Subway	83.3	61.5	90.0	95.0	74.0	30.0
	Surface	79.6	68.8	88.4	88.0	73.0	28.0
	Difference	3.7	7.3				
July 14–20	Subway	83.2	51.6	95.0	69.0	72.0	36.0
	Surface	84.2	48.7	100.0	80.0	71.6	32.5
	Difference	1.0	2.9				
July 21–27	Subway	82.4	50.7	90.6	85.0	70.0	31.5
	Surface	76.3	48.6	84.0	81.0	67.6	21.0
	Difference	6.1	2.1				
July 28–Aug. 2	Subway	81.2	55.7	88.6	91.0	67.0	28.5
	Surface	74.7	59.6	85.0	86.0	62.8	32.0
	Difference	6.5	3.9				
Aug. 4–10	Subway	83.4	64.4	88.2	86.0	71.5	52.5
	Surface	78.2	69.5	88.2	93.0	70.0	31.0
	Difference	5.2	5.1				
Aug. 11–17	Subway	81.5	59.0	89.0	85.0	69.5	34.0
	Surface	72.8	70.3	88.0	100.0	59.0	38.0
	Difference	8.7	11.3				
Aug. 18–24	Subway	81.2	55.8	87.8	84.5	68.0	35.0
	Surface	76.9	59.5	90.0	83.0	65.0	34.5
	Difference	4.3	.7				
Aug. 25–31	Subway	79.5	57.1	88.5	94.0	67.2	30.0
	Surface	72.0	62.7	81.9	100.0	63.0	33.5
	Difference	7.5	5.6				
Sept. 1–7	Subway	79.3	54.5	85.0	84.0	70.0	38.0
	Surface	71.8	61.4	77.5	92.0	66.2	39.0
	Difference	7.5	6.9				
Sept. 8–14	Subway	78.4	52.0	84.5	85.0	61.0	26.0
	Surface	66.5	59.0	79.5	88.5	52.8	21.5
	Difference	11.9	7.0				
Sept. 15–21	Subway	78.1	62.2	84.2	89.0	63.2	33.5
	Surface	70.2	73.9	76.5	99.0	60.5	43.0
	Difference	7.9	11.7				
Sept. 22–28	Subway	76.0	40.5	84.2	72.5	59.2	22.0
	Surface	66.0	45.0	81.2	74.2	47.8	28.0
	Difference	10.0	4.5				
Sept. 29–Oct. 5	Subway	78.0	52.6	83.8	79.0	68.8	38.0
	Surface	72.1	57.7	81.8	91.0	64.1	33.0
	Difference	5.9	5.1				
Oct. 6–12	Subway	74.4	42.6	82.2	62.0	59.0	24.0
	Surface	63.4	51.2	80.0	87.0	51.7	26.0
	Difference	11.0	8.6				

TABLE III — *Continued*

Date, 1905.	Place.	Average		Maximum		Minimum	
		Temperature.	Humidity.	Temperature.	Humidity.	Temperature.	Humidity.
Oct. 13–19	Subway	73.6	53.2	81.7	80.0	60.9	29.0
	Surface	63.0	61.6	76.8	93.0	45.8	31.5
	Difference	10.6	8.4				
Oct. 20–26	Subway	67.3	44.2	79.0	90.0	49.9	23.0
	Surface	53.7	59.5	69.1	98.5	42.2	28.0
	Difference	13.6	15.3				
Oct. 27–Nov. 2	Subway	65.6	42.3	74.1	76.5	48.8	21.0
	Surface	49.4	56.0	59.0	90.0	38.9	28.5
	Difference	16.2	13.7				
Nov. 3–9	Subway	64.6	42.5	73.0	77.0	50.8	26.0
	Surface	50.1	58.9	58.5	88.0	41.5	33.0
	Difference	14.5	16.4				
Nov. 10–16	Subway	60.8	34.6	71.0	63.0	41.8	15.0
	Surface	42.3	51.2	58.0	86.0	24.0	10.0
	Difference	18.5	16.6				

The lowest temperature recorded at Canal Street up to January 1 was 30°. The outside temperature at the same time was 14°, giving a difference of 16°. At the same time, the temperature at the Brooklyn Bridge and Astor Place stations was 54°. Or, in other words, the Brooklyn Bridge station was 40° warmer than the outside air, while the Canal Street station was but 16° warmer.

The express stations, with the exception of 96th Street, which was exceptionally open to the outside atmosphere, were all warmer than the local stations in their vicinity.

The coolest stations were those which were most open to the street; the hottest the most closed.

Figure 6 shows variations of temperature at some stations recorded by the thermographs.

Humidity

The relative humidity in the subway was generally less than that out of doors, but the temperature of the dew point was higher. This is shown in Figure 7. In other words, the actual weight of aqueous vapor present was greater in the subway than outside, but it appeared to be less in the subway than in the streets.

The humidity in the subway varied with the humidity out of doors (see Fig. 8).

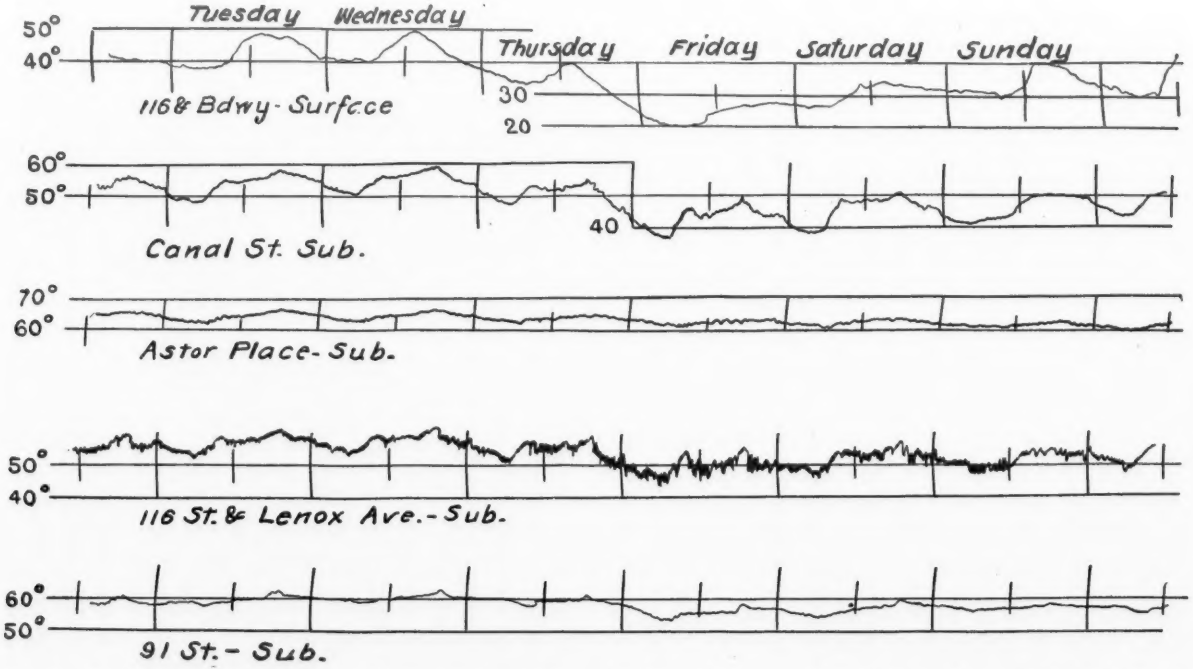

FIG. 6.—SYNCHRONOUS VARIATIONS IN TEMPERATURE AT DIFFERENT SUBWAY STATIONS AND IN THE STREETS, FOR ONE WEEK, AS SHOWN BY THERMOGRAPHS

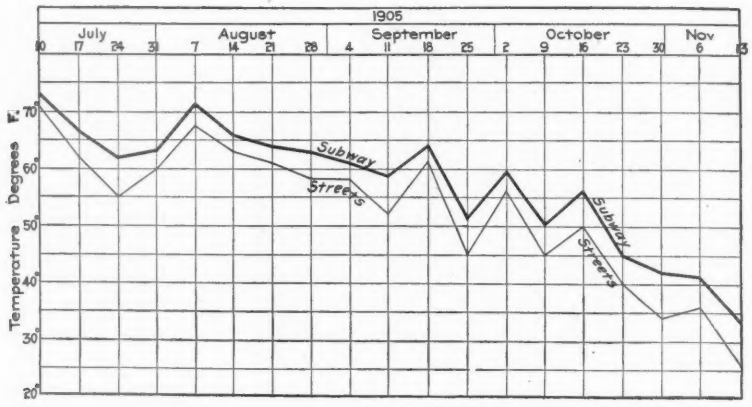

FIG. 7.—WEEKLY AVERAGE TEMPERATURE OF THE DEW POINT IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905

There were no fogs nor mists in the subway. A faint haze was not uncommon.

The average relative humidity for the subway for July and August was 57.5 per cent.; for the outside air, 60.6 per cent.; difference, 3.1 per cent.

The greatest average relative humidity occurred during the week when the average temperature was highest. During this period the relative humidity averaged 64.4 per cent.

Condensed records of humidity are given in Table III.

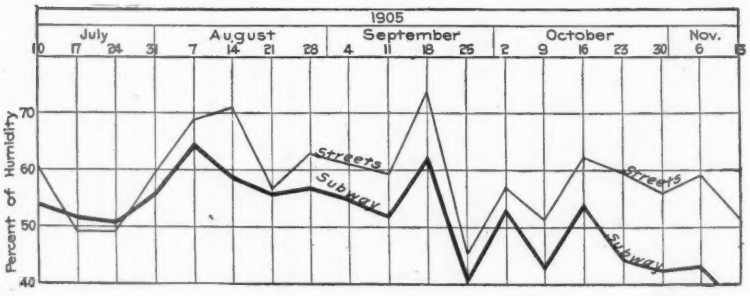

FIG. 8.—WEEKLY AVERAGE RELATIVE HUMIDITY IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905. THESE AVERAGES ARE MADE UP OF 47,456 OBSERVATIONS

CHEMICAL CONDITION OF THE AIR

The chemical analyses of air were confined chiefly to determinations of carbon dioxide, for it was thought that no other test could give such a correct knowledge of the extent to which the air was vitiated by respiration, and none could be made on such a large scale as was wanted with so little probability of error.

Methods of Analyses

Analyses for Carbon Dioxide.—The samples of air for analysis for carbon dioxide were collected in large, round-bottom flasks, varying in capacity from 2,000 c.c. to 2,600 c.c., made especially for the purpose.

Experiments proved that titrations could be made much more accurately in round-bottom flasks than in the Erlenmeyer flasks usually employed, since the faintest pink color could readily be detected by giving the flask a rotary motion and observing the color through the depth of the liquid as it spread in a thin film upon the sides of the flask.

Each flask was provided with a well-fitting, two-hole rubber stopper, fitted with glass plugs. Before being used, the flasks were boiled with sulphuric acid to remove any free alkali which may have been present, and then carefully rinsed and standardized.

Six of these flasks were fitted into a basket, which was carried by the collector. A large football pump, with the valve reversed, to pump air from the flasks, was employed; and this, with about 10 feet of rubber tubing, a thermometer, and a notebook, completed the collector's outfit. This apparatus is shown in Figure 9.

When it was desired to collect a sample, the basket was opened and the stopper removed from one of the flasks. The free end of the rubber tubing was then inserted into the flask as far as the bottom. This done, the operator removed to a distance with his pump and pumped air from the flask for about four minutes. This amount of pumping was capable of removing about eight times the volume of air in the flask, and provided for the collection of a proper sample.

After the sample was collected, the stopper was replaced in the flask, the temperature noted, and the data observed which were to fix the identity of the sample.

The samples were usually analyzed on the day of collection or the day after. Experiments showed that no appreciable change took place by allowing a sample to stand for twenty-four hours before analyzing.

On its arrival at the laboratory, the flask was placed in an upright position on a suitable rest and one of the glass rods removed from the stopper. The stopper was then gently pressed down until it reached a point marked on the neck of the flask at which its capacity had been calibrated.

A pipette was next inserted through the hole in the stopper and 20 c.c. of standard barium hydroxide, to absorb the CO_2, allowed to flow

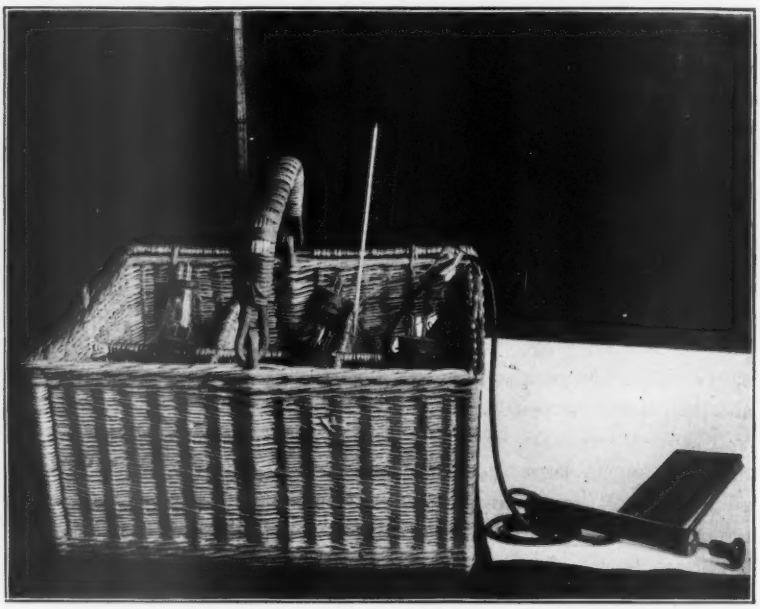

FIG. 9.—APPARATUS USED FOR COLLECTING SAMPLES OF AIR FOR CARBON DIOXIDE ANALYSES

into the flask with a few drops of plenolphthalein. The solution was allowed to stand, with occasional shaking, for one hour.

The delivery tube of a special burette was then inserted into the flask through one of the holes in the stopper, and the excess of barium hydroxide titrated with standard oxalic acid. The glass rod in the second hole of the stopper was removed from time to time to relieve the pressure. One cubic centimeter of this oxalic acid was equivalent to one-tenth of a cubic centimeter of carbon dioxide. From the quantity of barium hydroxide used, the amount of carbon dioxide in the original

sample of air was calculated, the volume being reduced to 0° C. and 760 mm. pressure.

Although the barium hydroxide solution remained practically constant from day to day, it was always standardized before each series of analyses.

The oxalic acid employed for making up the standard solution was tested by titrating with standard potassium permanganate and found to be satisfactorily pure.

The bottle in which the standard solution of barium hydroxide was kept was provided with a safety bottle containing pumice and caustic soda and a rubber bulb, which allowed the liquid to be forced up into the pipette instead of filling the latter by suction.

The burette used for titration was especially made for the purpose, and had a delivery tube 9 cm. long, which in use projected well into the flask of air.

Inasmuch as the manner in which the sample was collected gave room for some error if the collector was inattentive or careless in his work, care was taken to collect check samples from time to time by the help of other assistants. This error was further guarded against by entrusting the collections only to persons who, by age and training, seemed certain to use proper care. One of the collectors held the rank of assistant engineer under the Municipal Civil Service Commission of the city. Another was an analytical chemist of long experience.

A sample of air which was taken to check the work of a collector gave the following results:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Collector's sample	3.54
Samples collected as a check	3.48
Difference	.06

Experiments were made to determine whether or not long standing of the barium hydroxide solution in contact with the flask would have any effect on the results. For this purpose four samples of outside air were collected at the same time and place, and the barium hydroxide solution allowed to remain in the flask for periods of from one to four hours. The results follow:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Titrated at the end of one hour	3.48
Titrated at the end of two hours	3.47
Titrated at the end of three hours	3.49
Titrated at the end of four hours	3.48

Experiments to ascertain whether or not any difference in the results would be obtained by adding the barium hydroxide to the flask at the time of collection gave results which follow:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Solution added at time of collection	4.33
Added four hours after collection	4.36

Another set of samples was taken and analyzed as follows:

No.	Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
1	Added barium hydroxide solution at time of collection	2.09
2	Added barium hydroxide solution at time of collection	3.02
3	Added barium hydroxide solution after eighteen hours	3.02
4	Added barium hydroxide solution after eighteen hours	3.11
5	Added barium hydroxide solution after eighteen hours (paraffined stopper)	3.13
6	Added barium hydroxide solution after eighteen hours (paraffined stopper)	3.22

Another set of samples was analyzed as follows:

No.	Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
1	Added barium hydroxide at time of collection	3.40
2	Added barium hydroxide at time of collection	3.56
3	Added barium hydroxide after twenty-four hours	3.44
4	Added barium hydroxide after twenty-four hours	3.57

Figure 10 shows the apparatus used for the absorption of carbon dioxide by barium hydroxide.

Analyses for Oxygen.—About eighty samples of air were analyzed for oxygen. The difference between the amount present in the subway and in the streets seemed so slight and uninstructive that the determinations were soon discontinued as a routine procedure.

FIG. 10. — APPARATUS USED FOR THE ABSORPTION OF CARBON DIOXIDE BY BARIUM HYDROXIDE IN THE CARBON DIOXIDE ANALYSES

The samples of air were collected in glass tubes of 300 c.c. capacity, closed at each end by glass stopcocks. The tubes were filled with oxygen-free water at the laboratory and taken to the point where the samples were to be collected. There the cocks were opened and the water allowed

to flow out, the desired sample of air taking its place. The cocks were then closed and the sample taken to the laboratory for analysis.

The oxygen was determined by absorption with phosphorus, according to the method of Lindemann. Hempel burettes and a Hempel pipette, constructed for solid absorbents, were employed. The phosphorus was specially prepared, and the pipette was kept covered to protect it from the action of light. The pipette, when in use, was immersed in water to maintain a constant temperature, and thus obviate any inaccuracy which might have been caused by temperature changes.

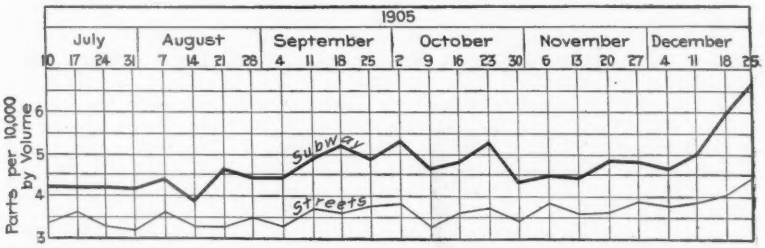

FIG. 11.—WEEKLY AVERAGE CARBON DIOXIDE FOR THE SUBWAY AND STREETS FROM JULY 10 TO DECEMBER 25, 1905, INCLUDING 1,772 DETERMINATIONS

CARBON DIOXIDE RESULTS

The carbon dioxide analyses produced results from which I derived the following conclusions:

The average amount of carbon dioxide in the subway was a little larger than in the air of the streets.

The average of all results was, for the subway, 4.81 volumes per 10,000 volumes of air, and for the streets, 3.67; difference, 1.14. This difference must be regarded as very slight (see Fig. 11).

The frequency with which the air was renewed could not be accurately calculated, for the reason that the number of passengers traveling in the subway was not known.

At no time or place was the amount of carbon dioxide large.

The greatest amount of carbon dioxide found in the subway was 8.89. This occurred in the tunnel between the Grand Central station and the 33d Street station, on December 27, 1905, at 6.02 P.M. At the same time there was a block, during which trains were stalled at all points in the vicinity. At the adjoining stations of 33d Street and Grand Central, the carbon dioxide was higher than usual at the same time, the amount at 33d Street being 7.84 and at Grand Central 7.87.

The carbon dioxide in the subway varied according to season, hour, place where the sample was collected, and other circumstances.

Season.—There was more carbon dioxide found in the autumn than

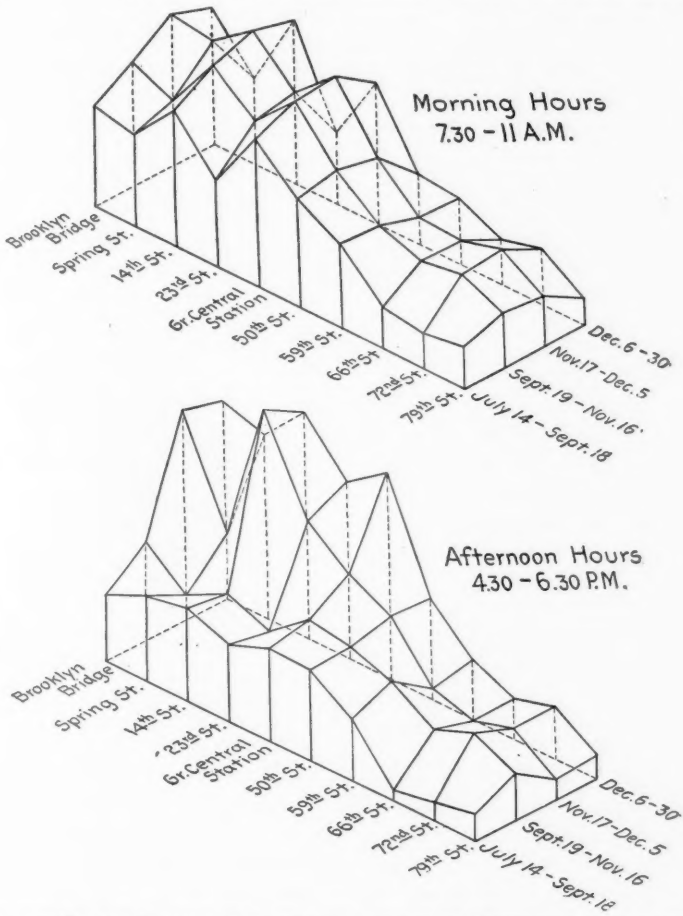

FIG. 12.—CARBON DIOXIDE AT DIFFERENT STATIONS AT DIFFERENT SEASONS DURING THE HOURS OF MAXIMUM TRAVEL IN THE MORNING AND AFTERNOON

in the summer or winter (see Fig. 12). It seemed likely that this was explainable largely on the ground that many more passengers were carried in autumn than in summer, and that in winter there was more wind in the streets and the subway, increasing the amount of ventilation.

Hourly Variations.—The amount of carbon dioxide varied in the subway at different hours of the day (see Fig. 13). These irregularities corresponded with the irregularities in the amount of travel which took place at different hours.

It is interesting to note that periodic changes in the amount of carbon dioxide occurred in the streets. In the streets the carbon dioxide was highest between 5.30 and 6 P.M., and lowest between 1 and 3 A.M. The amount increased from a minimum in the early morning hours to about 9 A.M. After this there was a fall to about 1.30 P.M., followed by a rise to the highest point of the day, which occurred between 5.30 and 6 P.M.

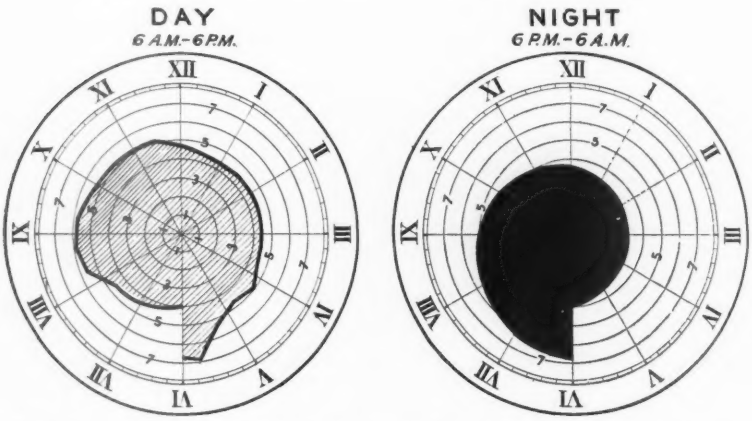

FIG. 13.—HOURLY VARIATIONS IN THE AMOUNT OF CARBON DIOXIDE IN THE AIR OF THE SUBWAY—AVERAGE OF 1,244 ANALYSES

The average range of CO_2 outside, as determined by hourly results, was .8 part per 10,000.

In the subway the greatest amount of carbon dioxide for the whole day also occurred between 5.30 and 6 P.M. Thereafter, there was a gradual fall to the lowest point, which was reached between 3 and 4 A.M.

From this lowest point the amount increased steadily to about 9 A.M., after which it fell irregularly to between 1 and 2 P.M.

The average for the whole day agreed closely with the average between 1 and 3 P.M.

In the late afternoon there was a rapid rise to the maximum for the day, which was reached at about 5.30 P.M.

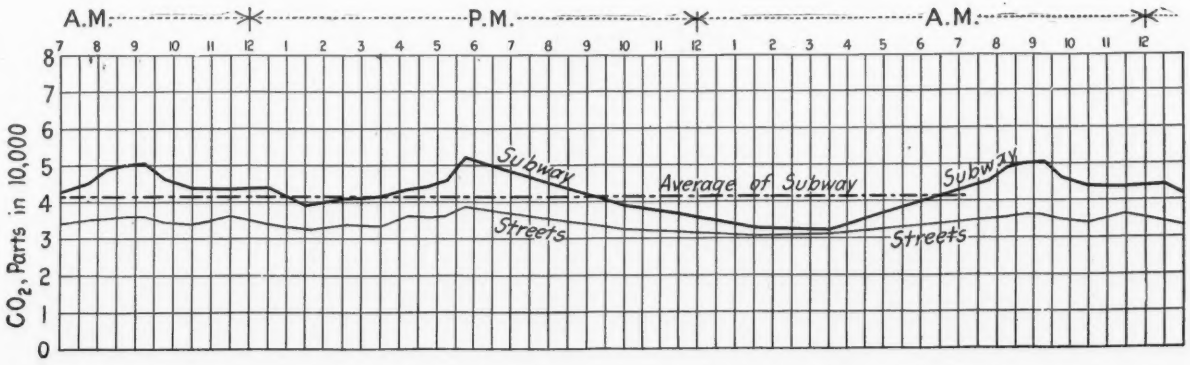
A.M.
P.M.
A.M.
7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
CO_2, Parts in 10,000
0 1 2 3 4 5 6 7 8
Subway
Average of Subway
Subway
Streets
Streets

FIG. 14.—VARIATION IN THE AMOUNT OF CARBON DIOXIDE IN THE SUBWAY AND STREETS AS DETERMINED BY HOURLY ANALYSES—AVERAGE OF 1,510 ANALYSES

TABLE IV

SIMULTANEOUS DETERMINATIONS OF CARBON DIOXIDE AT AND BETWEEN STATIONS IN THE SUBWAY. THE NUMBER OF ANALYSES INCLUDED IN THIS TABLE IS 442

Date, 1905.	Point of observation.	CARBON DIOXIDE.	
		Found.	Excess.
July 31–August 4	Between Fulton Street and Brooklyn Bridge stations	4.26	
	Average for Fulton Street and Brooklyn Bridge stations	4.07	.19
	Between Brooklyn Bridge and Worth Street stations	4.35	
	Average for Brooklyn Bridge and Worth Street stations	4.37	—.02
	Between Worth Street and Canal Street stations	4.13	
	Average for Worth Street and Canal Street stations	4.29	—.16
	Between Canal Street and Spring Street stations	4.18	
	Average for Canal Street and Spring Street stations	4.47	—.29
	Between Spring Street and Bleecker Street stations	4.28	
	Average for Spring Street and Bleecker Street stations	4.40	—.12
	Between Bleecker Street and Astor Place stations	4.57	
	Average for Bleecker Street and Astor Place stations	4.61	—.04
July 29–August 5	Between Astor Place and 14th Street stations	4.68	
	Average for Astor Place and 14th Street stations	4.77	—.09
	Between 14th Street and 18th Street stations	4.46	
	Average for 14th Street and 18th Street stations	4.57	—.11
	Between 18th Street and 23d Street stations	4.17	
	Average for 18th Street and 23d Street stations	4.27	—.10
July 28–August 2	Between 28th Street and 33d Street stations	4.12	
	Average for 28th Street and 33d Street stations	3.99	.13
	Between 33d Street and Grand Central stations	4.48	
	Average for 33d Street and Grand Central stations	4.23	.25
July 28–August 1	Between Grand Central and Times Square stations	4.73	
	Average for Grand Central and Times Square stations	4.46	.27
	Between Times Square and 50th Street stations	4.44	
	Average for Times Square and 50th Street stations	4.27	.17
	Between 50th Street and 59th Street stations	4.07	
	Average for 50th Street and 59th Street stations	3.99	.08
December 14–23	Between Fulton Street and Brooklyn Bridge stations	6.31	
	Average for Fulton Street and Brooklyn Bridge stations	6.21	.10
December 14–26	Between Canal Street and Spring Street stations	6.06	
	Average for Canal Street and Spring Street stations	5.92	.14
December 15–22	Between 14th Street and 18th Street stations	6.74	
	Average for 14th Street and 18th Street stations	6.55	.19
December 26–27	Between 33d Street and Grand Central stations	7.21	
	Average for 33d Street and Grand Central stations	6.82	.39
December 15–22	Between Grand Central and Times Square stations	6.55	
	Average for Grand Central and Times Square stations	6.21	.34
December 13–21	Between 66th Street and 72d Street stations	4.78	
	Average for 66th Street and 72d Street stations	4.75	.03
December 28	Under Central Park, south of 110th Street station	6.18	
	At 110th Street station	5.45	.73
December 29	Under Harlem River	6.30	
	Mott Avenue station	4.58	1.72
Mean CO_2 between stations		5.05	
Mean CO_2 at stations		4.87	.18

The difference between the least and greatest amounts of carbon dioxide was, according to these hourly averages, two parts per 10,000.

Figure 14 shows the variation in the amount of CO_2 in the subway and streets as determined by hourly results.

Differences in Different Parts of the Subway.—There was more carbon dioxide at express stations than at local stations, except at the especially open express station at 96th Street.

Among the principal express stations, the largest average amount of carbon dioxide was found at 14th Street. Then came the Brooklyn Bridge, Grand Central, 72d Street, and 96th Street stations, in the order named.

There was more carbon dioxide between stations than at the adjoining stations, although in most cases this difference was very little. The results of 442 analyses showed this average difference to have been .18 parts per 10,000, with a range of from .29 to 1.72. Data relating to this subject are given in Table IV.

Marked differences occurred in the amount of carbon dioxide found at points above and below 50th Street. The average of all results which were capable of being taken into account to show this difference demonstrated that the air from 50th Street uptown was much purer than the air from 50th Street downtown. This is shown in Table V.

TABLE V

CARBON DIOXIDE IN THE SUBWAY NORTH AND SOUTH OF FIFTIETH STREET THE NUMBER OF ANALYSES INCLUDED IN THIS TABLE IS 1,182

FROM FIFTIETH STREET DOWNTOWN

1905.	Brooklyn Bridge.	Spring Street.	Fourteenth Street.	Twenty-third Street.	Grand Central.
July 14–September 18	1.14	1.08	1.39	0.97	1.46
September 19–November 16	1.34	1.03	1.50	1.17	1.61
November 17–December 5	2.17	1.51	2.58	1.77	1.91
December 6–December 30	2.01	1.62	2.37	1.38	2.08
	1.66	1.31	1.96	1.32	1.76

TABLE V — *Continued*

FROM FIFTIETH STREET UPTOWN

	Fiftieth Street.	Fifty-ninth Street.	Sixty-sixth Street.	Seventy-second Street.	Seventy-ninth Street.
July 14–September 18	1.20	.88	.31	.32	.42
September 19–November 16	1.26	.97	.71	.86	.61
November 17–December 5	2.27	.71	.63	.82	.42
December 6–December 30	1.02	.75	.52	.65	.30
	1.44	.83	.54	.66	.44

Differences in the elevation above the pavement at which samples were taken made little difference in the amount of CO_2 found in the subway. These differences are indicated in Table VI.

TABLE VI

CARBON DIOXIDE AT DIFFERENT ELEVATIONS ABOVE THE PLATFORMS OF SUBWAY STATIONS

Date, 1905.	Place.	Time.	Two feet.	Four feet.	Six feet.	Eight feet.	Ten feet.	Average.
August 17	14th Street station . . .	2.00– 2.15[P]	4.01	3.48	4.11	4.24	. .	4.05
August 18	Grand Central station .	9.45–10.10[A]	5.35	4.83	4.73	4.71	4.73	4.87
	Brooklyn Bridge station	1.40– 2.15[P]	4.21	4.41	4.36	4.18	4.18	4.27
August 19	Grand Central station .	9.35–10.00[A]	4.84	4.61	4.59	4.69	4.71	4.69
August 22	14th Street station . . .	10.45–11.10[A]	4.72	4.97	4.69	4.90	4.60	4.78
August 23	Grand Central station .	10.00–10.30[A]	4.63	4.67	4.74	4.59	4.65	4.66
August 24	Brooklyn Bridge station	9.55–10.25[A]	4.91	4.92	4.64	4.50	4.74	4.74
Mean CO_2 at different heights			4.67	4.61	4.55	4.54	4.60	4.58
Mean of all observations			4.58	4.58	4.58	4.58	4.58	4.58
Departure of mean for each height from mean of all observations			+.09	+.03	−.03	−.04	+.02	. .

The CO_2 in the air of the cars in summer, when the windows and front doors were open and the travel comparatively light, was not far different from the air of the subway itself.

OXYGEN RESULTS

The samples of air which were analyzed for oxygen were collected from 9.30 A.M. to 5.30 P.M., between the Brooklyn Bridge and 96th Street stations.

The average amount of oxygen found in the air of the streets was 20.71 per cent.; in the subway, 20.60 per cent.; difference, .11 per cent. The least amount found in the subway was 20.25 per cent.

BACTERIAL CONDITION OF THE AIR

The studies concerning the micro-organisms in the subway related chiefly to the number and origin of the bacteria and molds. It was not practicable within the time and scope of the investigation to determine the various species of bacteria present, but the principal sources of many of them were investigated indirectly with fairly satisfactory results.

Quantitative Methods of Analysis

The bacteria were collected by allowing them to settle from the air on circular plates, or Petri dishes, 3½ inches, or about 9 cm., in diameter, containing a standard agar culture medium, and by collecting them from the air by means of sand filters.

The Plate Method.—The plates containing the culture medium were carried from the laboratory to the points of observation in a handbag. The plates and covers were fastened together by means of elastic bands, each pair separated from other pairs by sterilized towels.

To make an observation, the plates were taken from the handbag and placed, usually, upon a bench about 18 inches from the pavement. The covers were then removed and kept off for fifteen minutes, or a fraction of this time, depending upon the observer's judgment of the numbers which would probably be found.

During the exposure of the plates, the observer removed to a distance and made the notes necessary to identify the observation.

The covers were then replaced, secured to their respective dishes by the rubber bands, and returned to the laboratory in the handbag. The plates were put into the incubator within two hours after exposure.

The plates were incubated at a temperature of 37° C. for forty-eight hours. The colonies of bacteria and molds which developed in this time were then counted. Care was taken to separate the two.

Most of the exposures were made at the subway stations at points as far removed from draughts as possible. Exposures out of doors were made, for the most part, on the line of the subway beyond the influence of subway air, and at an elevation of about 3 feet above the sidewalk.

In all, about 2,800 exposures were made.

The agar culture medium was prepared with Liebig's extract of beef and 5 per cent. agar.

The reaction of the medium, after preliminary trials to ascertain the

FIG. 15.—COLONIES OF BACTERIA GROWN ON A PLATE EXPOSED FOR FIFTEEN MINUTES AT THE GRAND CENTRAL SUBWAY STATION

optimum, was fixed at ½ to 1 per cent. acid to phenolphthalein. In preparing the plates for use, 10 c.c. of the agar medium was poured, and the plates then put into the incubator for twenty-four hours. Plates which developed colonies in this time were contaminated and not used.

All the bacteriological plates were exposed in duplicate. The results reported were averages of the counts of two plates in every instance.

Preliminary trials of different media and at different periods of incubation showed that a gelatin medium kept for several days at what is generally termed "room temperature" would often develop more colonies than an agar medium developed at body temperature. There

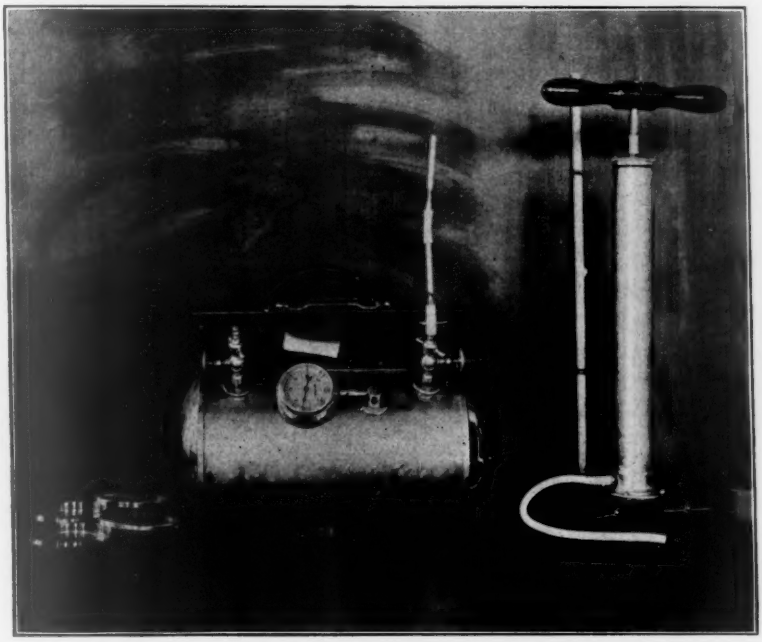

FIG. 16.— PORTABLE APPARATUS USED FOR ESTIMATING THE NUMBERS OF MICRO-ORGANISMS IN A MEASURED VOLUME OF AIR

were probably several reasons for this: The higher temperature of the body undoubtedly kept many delicate air organisms from growing. Gelatin was a more favorable solidifying agent than agar. An incubation period of more than forty-eight hours seemed to be essential to the growth, to visible colonies, of some bacteria in artificial culture media.

The chief objection to the gelatin-room-temperature method was that gelatin melted at a temperature which made it unsuitable for summer use, became too easily liquefied by certain bacteria, and was likely to be too rapidly overgrown with molds.

The procedure adopted seemed to be the most practicable under the circumstances. It had also the merit of being capable of duplication at any time and place with a considerable degree of accuracy.

The numbers of bacteria which actually existed in the air must have been largely in excess of the numbers found, but it was not feasible to ascertain how great was this difference.

Colonies of bacteria grown in a plate exposed for fifteen minutes to the air at the Grand Central subway station are shown in Figure 15.

The Filter Method.—The collection of micro-organisms by the use of filters provided means for estimating the numbers of bacteria and molds recoverable from a measured volume of air. After a considerable amount of preliminary work, the method adopted was substantially that employed by Sedgwick, Prudden, and others, and described in "Studies from the Department of Pathology, College of Physicians and Surgeons," New York, Volume VII, 1900 (see Fig. 16).

The filters consisted of glass tubes about 13 cm. long and 0.5 cm. inside diameter. At one end the filtering material was held in place by a small plug of wire gauze, and at the other, when the filter was not in use, by a plug of cotton.

Various filtering materials were tried in experiments preliminary to the adoption of a standard method, especially the sugar medium of Sedgwick, proposed before the Society of Arts in 1888 (see Sedgwick and Tucker, "Methods for the Biological Examination of Air," *Proceedings of the Society of Arts,* Boston, 1888). In the subway work the advantages of a soluble medium were apparently more than offset by the care with which the sugar required to be sterilized and kept dry.

The filtering medium finally adopted was sand. The depth of sand was about 5 cm. Most of the grains were about half a millimeter in diameter. The particles were largely quartz. Two filters were always arranged in tandem (see Fig. 17).

Air was made to pass through the filters, in most cases by means of an exhaust pump of accurate construction, whose action had been carefully tested. Sixty-six strokes pumped 20 liters, and this was the amount usually pumped in each case.

Where it was not feasible to use the air pump, a brass vacuum cylinder of about 600 cubic inches, or 10 liters, capacity, fitted with a pressure gauge and suitable stopcocks, was employed, as devised by Prudden. The cylinder was 266 cm. long and 177 cm. in diameter, and was fitted into a neat leather bag with suitable openings, through which the gauge could be read and the filters connected.

Before using the cylinder, the air was exhausted from it and the stopcocks closed. It was then placed in the handbag and taken to the place where the observation was to be made. The filters were then connected to the cylinder by means of short rubber tubing, the pressure

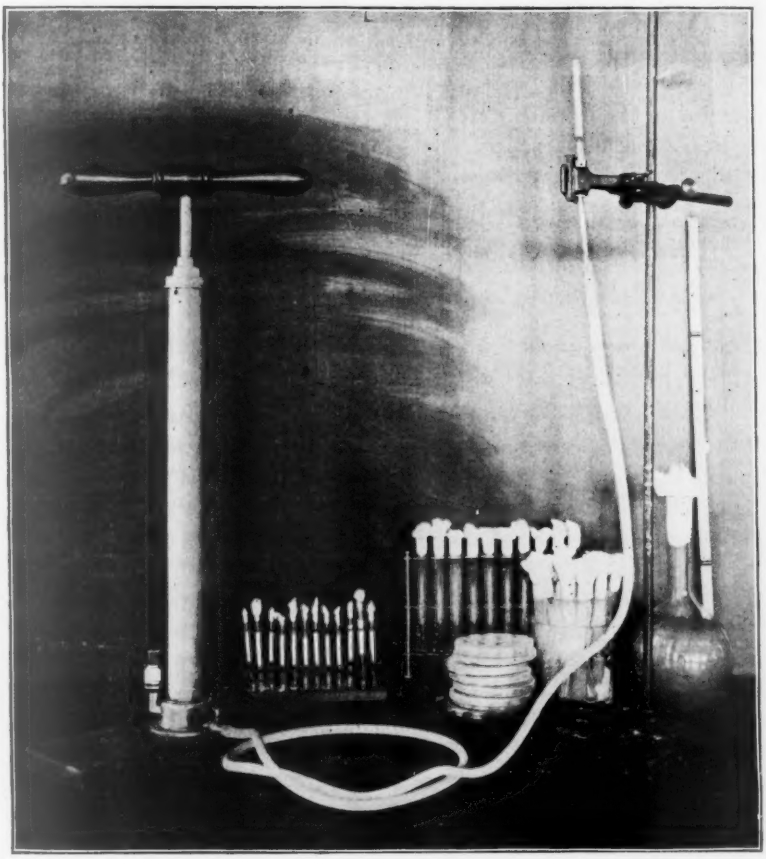

FIG. 17.—APPARATUS USED FOR ESTIMATING THE NUMBERS OF MICRO-ORGANISMS IN A MEASURED VOLUME OF AIR

gauge read, and the air allowed to flow into the cylinder through the filters. When the desired quantity of air had been filtered, the cocks were closed, the filters removed, and the gauge read.

Upon returning to the laboratory the sand was emptied from the

first filter into a test tube containing 10 c.c. of sterile water, and thoroughly agitated.

The water, with the organisms which had been rinsed from the sand, was then plated in agar and incubated for forty-eight hours at 37° C. and then counted.

The second filter was treated in the same way. Molds were excluded from the count.

Another method, and the one which was adopted finally, discarded the use of the distilled water. The sand from a filter was poured into a tube of melted agar, the tube agitated and then poured into a Petri dish, leaving the sand behind. A second tubeful of agar was then poured upon the sand remaining in the first tube. This was then agitated and the agar and sand both poured into a second Petri dish. The two Petri dishes were then incubated.

Most of the bacteria found were caught in the first filter.

Additional Bacterial Work

Beside the routine estimates of the number of bacteria recovered from the air, special studies were made of the length of life of the pneumococcus in the subway, the numbers of bacteria in subway and other dusts, the action of lubricating oil upon bacteria, the kinds of molds present, and the efficiency of various commercial deodorants and germicides intended for subway use.

The Longevity of the Pneumococcus.—The longevity of the pneumococcus was tested by drying upon a flat piece of broken trap rock about 20 c.c. of sputum from a patient suffering from lobar pneumonia in the congestive stage. The presence of the pneumococcus in a viable condition was tested in the beginning of the experiment and at the end of every two or three days. The vitality was determined by culture methods and by inoculating small portions of the moistened sputum into guinea pigs.

The rock with the dried sputum was taken into the subway and set upon the top of a clean iron beam at a little distance from the end of a station platform. Small parts of the mass were taken from day to day for examination, but the main body of sputum was not taken out of the subway until the end of the experiment.

The Numbers of Bacteria in Dusts.—Specimens of dust which had gathered upon recently painted beams and other clean, dry surfaces were

collected in large, sterile test tubes and Erlenmeyer flasks and taken to the laboratory. Here a small, weighed portion of the dust was mixed with from 50 to 500 c.c. sterile water. One cubic centimeter, and fractions thereof, of the water were then sown in the agar culture medium already described. The agar was incubated for forty-eight hours at 37° C. and counted. From these counts the numbers of bacteria per gram of dust were calculated.

Action of Oil on Bacteria.—The possibility that the lubricating oil which was copiously used in the first few months after opening the subway might have a germicidal or cultural effect upon bacteria was inquired into.

Specimens of oily wood, stone, and refuse paper from the tracks were taken to the laboratory and examined for the numbers of bacteria which they contained. The oil itself was tested for its action upon various species of bacteria.

Kinds of Molds.—Although it was not feasible to study the kinds of bacteria, because of the great similarity in their forms and cultural behavior, it was practicable to determine a few of the molds present. This was done by fishing from the mixed colonies of molds and bacteria which developed upon the plates exposed in the subway. From specimens obtained in this way, pure cultures were made upon various media suitable for the propagation of the molds.

No attempt was made to make this work exhaustive, since it seemed doubtful whether a complete knowledge of the numbers and kinds of molds in the subway, had it been obtainable, would have thrown much light upon the problems in hand.

Efficiency of Deodorants and Disinfectants.—The efficiency of different chemical compounds advocated by various persons to purify the air of the subway was examined into. They were tested both with reference to their capacity for destroying unpleasant odors and bacteria.

The capacity of these compounds to destroy odors was tested in the laboratory by producing unpleasant odors in suitable closed chambers, and then introducing the compound in different amounts and under different circumstances of temperature and humidity.

The disinfectant properties of the compounds were tested by allowing them to act upon bacteria in colonies on culture media, in films and emulsions, on toothpicks, and on freshly impregnated cotton threads. The germs used in these experiments were the typhoid bacillus and the colon bacillus, the pneumococcus and the Staphylococcus pyogenes albus.

The laboratory procedures were such as are usually employed in careful work of this kind.

Results

A careful examination of the bacterial data collected in these studies, excepting the data which relate to the dust, has led me to the following conclusions:

Numbers of Bacteria in Subway and Streets Compared.—There were, on an average, more than twice as many bacteria found in the air of the streets as in the air of the subway, excepting after rains, when fewer were found outside than inside.

The average numbers of bacteria which settled from the air in fifteen minutes, and were subsequently enumerated, were, in the subway, 500; outside, 1,157; difference, 657 (see Figs. 18 and 19).

The average number of bacteria found by filtering the air was 3,200 per cubic meter in the subway and 6,500 in the streets; difference, 3,300.

Molds.—The molds recovered from the air by filters were almost always less numerous in the subway than out of doors. The maximum number of molds found was 1,100 per cubic meter. This observation was made in the tunnel under Central Park.

The average ratio of molds to bacteria, as determined by the observations with filters, was 1 to 40 in the subway.

Effects of Wind in the Streets.—The wind in the streets had a decided effect upon the numbers of bacteria collected from the air, both inside and outside of the subway. The averages show that five times as many were recoverable from the air in the streets with a wind of 18 miles per hour as with a wind of 9 miles.

Origin of the Bacteria.—No attempt was made to identify the different kinds of bacteria. To have undertaken to name the species, even with a great deal more time than was available and a special corps of bacteriologists, would probably have produced little result. Nevertheless, the conclusion was reached that most of the bacteria in the subway come from the streets. The principal reasons for holding this view follow:

1. The numbers of bacteria recovered from the air of the subway varied with the more decided changes in the streets.

2. The bacteria were more numerous at the subway stations near the stairways than at the remote ends of the platforms.

3. In the subway stations, the bacteria were more numerous on that side of the road toward which the wind blew than on the opposite side.

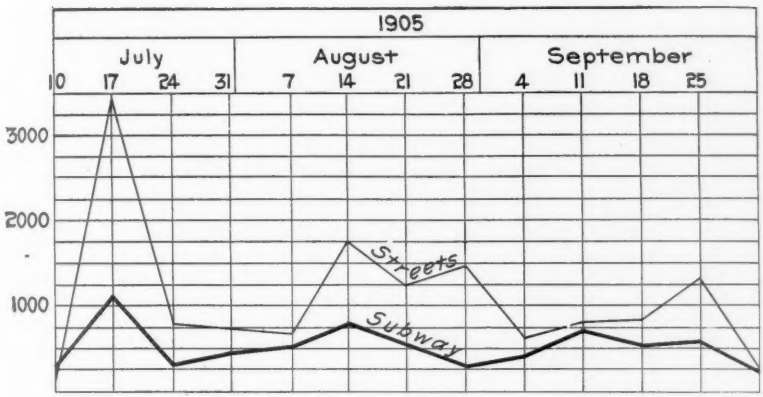

FIG. 18.—AVERAGE NUMBERS OF BACTERIA WHICH SUBSIDED FROM THE AIR PER SQUARE FOOT PER MINUTE, AS DETERMINED BY THE PLATE METHOD, IN THE SUBWAY AND STREETS FROM JULY 10 TO OCTOBER 2, 1905. THE NUMBER OF SAMPLES REPRESENTED IS 2,742

4. There were more bacteria at the arrival ends of the platforms of the stations than at the departure ends.

5. Street dirt, probably containing large numbers of bacteria, was often carried down the stairways into the subway by inrushing currents of air and by the passengers.

Although it seemed likely from these reasons that most of the bacteria in the air of the subway were derived from the streets, there was ground for concluding that some, and among them objectionable kinds, were due to the presence of the people. It is practically certain when great crowds are packed together, as they often were in some stations and most cars, that dangerous bacteria are, at least occasionally, transmitted

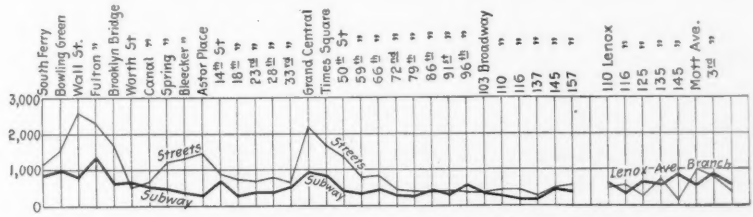

FIG. 19.—AVERAGE NUMBERS OF BACTERIA WHICH SETTLED FROM THE AIR UPON EACH SQUARE FOOT PER MINUTE AT DIFFERENT SUBWAY STATIONS AND IN THE STREETS. THE NUMBER OF SAMPLES REPRESENTED IS 2,753

from person to person. An obvious feature of this danger lies in the fact that people talk, cough, and sneeze into one another's faces at extremely short range under such circumstances.

Effect of Trains.—The numbers of bacteria in the air of the subway varied with the amount of travel. They were most numerous when the trains were most numerous, and fewest when the trains were fewest.

When the trains were blocked many of the bacteria disappeared from the air. In one case the bacteria were reduced from 1,800 to 250 in about an hour in this way. This is shown in Table VII.

TABLE VII

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY A BLOCKADE LASTING AN HOUR, NOVEMBER 11, 1905

Place.	Time.	MICRO-ORGANISMS PER CUBIC METER OF AIR.	
		Bacteria.	Molds.
110th Street and Broadway station, north end, east platform. Soon after the collection of the first sample all trains stopped running. Finally, no passengers in subway	10.20ᵃ	1,300	0
	10.37ᵃ	750	0
	10.55ᵃ	400	0
	11.15ᵃ	250	0
Average	..	700	0

Effect of Sweeping.—The effect of sweeping the platforms with brooms, without first taking precautions against raising dust, was noted. On one occasion the numbers of bacteria were increased by sweeping from about 5,000 to 13,000, and remained above 8,000 for at least three-quarters of an hour—the time covered by the observation. The effect of sweeping is shown in Table VIII.

Effects on Harmful Micro-Organisms.—It was not found that any harmful germs were capable of multiplying in the oil which dripped from the machinery of the cars upon the broken stone ballast and wooden ties of the roadbed.

The lubricating oil apparently removed and collected from the air large numbers of bacteria, many of which soon ceased to exist.

The pneumococcus was found capable of retaining its virulence in dried sputum in the subway for twenty-three days. This is in marked contrast to the findings of Wood, who reported that the pneumococcus was killed in four hours in sunlight.

TABLE VIII

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY SWEEPING THE PLATFORMS IMPROPERLY

Place.	Time.	Micro-organisms per Cubic Meter of Air.		Ratio of bacteria to molds.
		Bacteria.	Molds.	
Fulton Street station, south end, west platform. Remote from openings to streets	10.25[a]	4,900	100	49 : 1
Porter began sweeping near by	10.41[a]	13,200	50	264 : 1
Still sweeping, but farther off	10.57[a]	8,100	0	. .
Still sweeping, middle of platform	11.12[a]	8,500	0	. .
Average	. .	8,600	38	226 : 1

With few exceptions, there were not so many bacteria in the air of the toilet rooms as in the rest of the subway. In some cases the numbers were much greater.

Inefficiency of Proprietary Disinfectants.—The proprietary disinfectants used in the toilet rooms had no germicidal or deodorizing value. Furthermore, they produced counter odors of a peculiarly unpleasant character.

Numbers of Micro-Organisms in Dusts.—The numbers of bacteria recovered from the dust of the subway averaged 500,000 per gram.

The largest number of bacteria found in subway dust was 2,000,000 per gram. Still greater numbers probably could have been found by selecting the specimens of dust toward this end.

For comparison with the numbers of bacteria found in dust from the subway, it is interesting to note that dust which had accumulated under similar circumstances in a Broadway theater contained 270,000 bacteria; in a new and fashionable hotel, 360,000; in a well-known Fifth Avenue church, 320,000; in the tallest office building in the city, 850,000; and in the attic of a country house one hundred and fifty years old, 110,000 bacteria per gram. The full results of these analyses are given in Table IX.

Dust which had accumulated in the subway contained over twice as many molds as dust collected in outside buildings. In the dusts the ratio of bacteria to molds was 89 to 1 for the subway, and 250 to 1 elsewhere.

TABLE IX

NUMBERS OF BACTERIA AND MOLDS FOUND IN ACCUMULATED DUSTS

Date, 1905.	Place.	Sample No.	Number Micro-organisms per Gram of Dust.		Ratio of bacteria to molds.
			Bacteria.	Molds.	
October 23	96th Street station	1	550,000	1,500	367 : 1.0
October 24	Grand Central station	2	1,000,000	2,500	400 : 1.0
October 25	14th Street station	3	2,000,000	500	4,000 : 1.0
October 26	Wall Street station	4	600,000	4,100	146 : 1.0
October 26	Brooklyn Bridge station	5	1,100,000	6,500	169 : 1.0
October 31	Columbia University station	6	81,000	1,600	51 : 1.0
November 1	Fulton Street station	7	1,000,000	3,500	286 : 1.0
November 2	South Ferry station	8	300,000	5,600	54 : 1.0
November 3	Times Square station	9	160,000	6,400	24 : 1.0
November 4	72d Street station	10	600,000	2,900	207 : 1.0
November 6	66th Street station	11	460,000	0	. . .
November 8	125th Street and Lenox Avenue station	12	650,000	6,500	100 : 1.0
November 9	Mott Avenue station	13	470,000	11,000	43 : 1.0
November 10	149th Street and Third Avenue station	14	440,000	8,700	51 : 1.0
November 11	110th Street and Broadway station	15	290,000	6,000	48 : 1.0
November 13	Columbus Circle station	16	190,000	1,100	173 : 1.0
November 14	23d Street station	17	160,000	2,300	70 : 1.0
November 15	Grand Central station	18	650,000	550	1,182 : 1.0
November 16	14th Street station	19	500,000	17,000	29 : 1.0
November 17	Brooklyn Bridge station	20	370,000	11,000	34 : 1.0
November 18	Wall Street station	21	270,000	12,000	23 : 1.0
November 20	50th Street station	22	150,000	11,000	14 : 1.0
November 21	South Ferry station	23	120,000	4,200	29 : 1.0
November 22	96th Street station	24	340,000	5,000	68 : 1.0
November 23	Brooklyn Bridge station	25	800,000	8,300	96 : 1.0
November 24	Times Square station	26	370,000	2,200	168 : 1.0
November 25	Grand Central station	27	650,000	2,300	283 : 1.0
November 27	14th Street station	28	300,000	14,500	21 : 1.0
December 5	South Ferry station	31	51,000	3,900	13 : 1.0
December 6	Canal Street station	34	230,000	6,500	37 : 1.0
December 4	Attic of house 150 years old, Hadley, Mass.	29	120,000	6,300	19 : 1.0
December 4	Attic of house 150 years old, Hadley, Mass.	32	110,000	5,600	20 : 1.0
December 4	Cellar of old Hadley house	33	52,000	120,000	1 : 2.3
December 7	A fashionable hotel	35	360,000	4,400	82 : 1.0
December 7	A Fifth Avenue church	36	320,000	5,800	35 : 1.0
December 8	A Broadway theatre	37	270,000	0	. . .
December 9	A downtown restaurant	38	1,200,000	0	. . .
December 9	Twentieth floor of an office building	39	850,000	1,500	567 : 1.0
December 9	Public ward of hospital	40	600,000	2,600	231 : 1.0
Average of thirty subway observations			500,000	5,600	89 : 1.0
Average of six New York buildings			600,000	2,400	250 : 1.0

ODORS

Odors were more or less prevalent at all times and at nearly all places in the subway. In some cases they were so faint as hardly to be noticeable, in others very decided.

The effects of the odors upon the passengers varied with the sensitiveness of the individual. To some persons the odors were exceedingly offensive, to others they were barely noticeable; many passengers soon became used to the odors and did not seriously object to them.

To persons unaccustomed to the subway the odors were unpleasant, and suggested that conditions existed which were injurious to health.

The odors were most apparent during hot, damp weather, at places where the greatest crowding occurred and where the least amount of ventilation took place.

Odors were far more often offensive in the cars than elsewhere, especially in the fall and winter months, when the windows were closed and the number of passengers was unusually large.

Methods of Investigation

An effort was made to ascertain the main causes of the odors. It was not possible to analyze them chemically or to measure them by other means than the senses, although samples of subway dust and air, when brought to the laboratory, often smelt unmistakably of the subway. By inspections in the subway and repair shops, by examining in the laboratory a large number of solid and liquid substances taken from the subway, and by attempting to duplicate the odors in closed chambers under different conditions of temperature and humidity, some of the causes of the odors were discovered.

Results of Investigating the Causes

The following conclusions are, in my view, justified by these studies:

Stone Ballast.—The stone ballast of the roadbed was responsible for part of the odor. This stone was made of broken trap rock, and its peculiarly slaty odor in the warm atmosphere of the subway was unmistakable. It could be most easily distinguished, especially at the more open stations, on damp days.

Frequently the odor of the trap was masked by other odors.

Lubricants.—The oil used in lubricating the wheels and machinery of the cars was one of the principal causes of odor. Large quantities of this oil were allowed to drip from the machinery upon the ballast and ties of the roadbed when the subway was first put in operation.

Samples of the oil were obtained for experiment. It was not feasible to determine by analysis its exact composition, but in other ways it was ascertained that it was composed chiefly of petroleum and fish oil.

The quantity of oil used in the subway in the first year of operation appeared larger than had ever been used on an equal length of road. It probably amounted to over 200 gallons per mile of road per month.

In addition to this oil, about 150 pounds of gear grease were used per mile per month.

Much of the oil and grease was heated on the bearings, and some of it was volatilized. The car journals, motor armature bearings, and motor axle bearings were sometimes raised to a temperature of from 100 to 170° F.

That the oil was distributed through the atmosphere of the subway was fully demonstrated. It was recovered from the dust by extraction with ether to the extent of 1.18 per cent. by weight.

Results of evaporation tests of the lubricating oil, according to the method of Gill, are given in the following tables:

Loss in Weight of Subway Oil by Evaporation — Air Temperature

Sample No.	Per cent. loss after twenty-four hours at 25–29.9° C.
1	0.31
2	0.35
3	0.45
Average	0.37

Loss in Weight of Subway Oil by Evaporation — Temperature of Parts Lubricated

Sample No.	Wheel Journals.	Axle Bearings.
	Per cent. loss after eight hours at 74–76° C.	Per cent. loss after eight hours at 110–115° C.
1	. .	6.93
2	1.57	8.04
3	1.08	7.65
4	1.86	7.77
5	1.86	9.22
Average	1.59	7.92

It will be noted that at air temperature there was a loss of 0.37 per cent., and 7.92 per cent. at 110° and 115° C. Under similar conditions whale oil, high grade fish and rape seed oils showed gains of from 1.01 to 5.39 per cent. at 74° and 76°, and losses of 0 to 2.65 per cent. at 110° and 115°, respectively.

Motors.—Odors were given off by the hot motors acting upon various more or less volatile substances other than oil and grease. Among these substances were the insulating material covering some of the electric wiring and the paint upon the motor cases.

Electric sparking produced the odors of ozone and nitrous oxide.

The hot brake shoes gave off a peculiar odor.

Disinfectants.—A pungent and unpleasant odor was produced by the proprietary disinfectants used in the toilet rooms. This odor was so penetrating that it was occasionally noticeable on the streets outside of the subway.

Tile Cement.—A strong and disagreeable odor was caused by an oily cement used in fastening decorative tiles in place at some of the stations. An ingredient of this cement was a cheap grade of fish oil. In order to disguise the fishy odor, creosote was freely mixed with the oil before mixing it with the cement. The result of these intermingled odors was peculiarly unpleasant. Fortunately, the odor of the cement, although very powerful at first, rapidly disappeared.

Hot Boxes.—Hot boxes, of which there were a considerable number when the road was first put in operation, at times produced a persistent and suffocating odor. Wool waste was used in packing the car journals, and when this caught fire its unpleasant smell could be distinguished through the subway for a long time.

Fuses.—Occasionally a fuse was blown out and its odor distributed up and down the line. When a fire occurred, as happened on a few occasions, the odor of smoke persisted in the part of the subway where the fire occurred for a surprisingly long period of time. In one case the odor was distinctly noticeable to passengers, as the cars passed the spot, three months after the fire had taken place.

Tobacco Smoke.—The odor of tobacco smoke was not uncommon at the subway stations. Rules existed against smoking in the subway, but they were not enforced. Lighted cigars, cigarettes, and pipes were occasionally carried even into the cars.

Concrete and Fresh Paint.—Odors from new concrete and fresh paint were often noticed. The former was persistent, the latter transient.

Odors of Human Origin.—Odors of human origin were sometimes present, but almost always close to people. They were most common during warm, damp weather and where there was much crowding. These odors often came from the clothing of the passengers. It was sometimes possible to learn the occupation of a workman by the odor of his clothes. Odors of coffee, garlic, bad teeth, liquor, cheese, and perfumery were some of the personal odors noticed.

The peculiar odor given off by clothing which had been hung in a kitchen was frequently noticed.

In fact, under the conditions of crowding, amounting frequently to close personal contact, it seemed that odors of practically every character connected with human existence were noticeable.

Excepting in rare instances, where ignorant employees were not kept under as strict supervision as their defective sense of decency required, the odors which permeated the general air of the subway did not point to conditions dangerous to health. Personal odors were detectible only at short range. When people are crowded so closely together that their breath and other body-odors are offensive, there is always danger that disease may be transmitted from one to another.

The toilet rooms were much neglected at the time of this investigation, and often gave rise to an unpleasant local odor.

DUST

The dust of the subway was made the subject of study because of its unpleasant features and the possibility that it might play a part in producing or aggravating respiratory diseases. Its possibilities for harm were to lie perhaps in its bacterial and physical composition.

Methods of Examination

The dust was examined microscopically, chemically, and bacteriologically, by a special method which was devised for determining the gross weight of dust in a measured volume of the air, and by an instrument for estimating the total number of floating particles present.

Microscopical and Chemical Examination.—The microscopical analyses were intended to show the shape of the particles and what could be ascertained in this way concerning their physical composition. The dust was examined under low powers of the microscope and with magnifications as high as 1,200 diameters.

It was possible, by means of a common horseshoe magnet held beneath a piece of paper sprinkled with the dust, and slowly moved from side to side, to distinguish particles of iron and steel. These metal particles could be made to rise on edge and reverse their position by changing the pole of the magnet presented to them.

The chemical analyses were intended to indicate the amount of iron, organic matter, silica, and oil.

Bacteriological Examination.—The bacteriological analyses were

intended to give some idea of the numbers of bacteria and molds present in dusts which collected at different points. The bacteriological method employed in this work has been already sufficiently explained.

Weight of Dust in Air.—At first the gross weight of dust in a measured volume of air was determined by means of a sugar filter, through which air was exhausted by means of an air pump. The amount

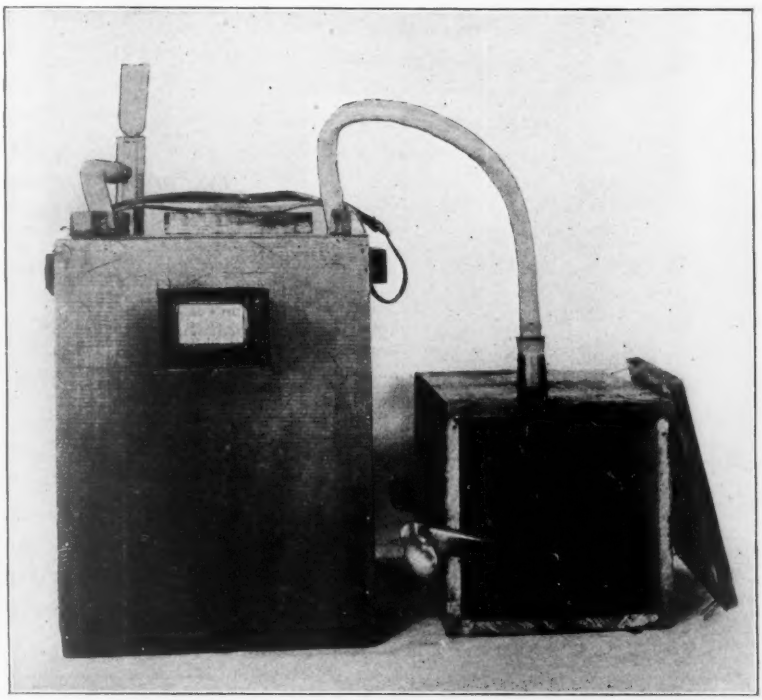

FIG. 20.—APPARATUS USED FOR ESTIMATING THE WEIGHT OF DUST IN A MEASURED VOLUME OF AIR

of air which it was desirable to pass through the filter proved to be too great for an air pump of ordinary capacity. After experimenting with nearly every pump and blower on the market which promised to serve the purpose, a small Root's blower was employed, the blower being operated, as an exhaust, by hand, by means of a crank. A test meter, manufactured by the American Meter Company, New York, was used to measure the air. The meter was examined and found to be accurate to within 1½ per cent. when used in this way.

The filter consisted of 10 c.c. of finely granulated sugar, contained in a glass funnel of 2.5 cm. diameter, with straight upper sides. The sugar rested upon a plug of wire gauze and was 5 cm. deep.

It was customary to pump 50 cubic feet, or 1.416 cubic meters, of air through a filter for each observation.

The apparatus was so connected that the air passed first through the filter, next through the meter, and finally through the Root's blower, which was, of course, run backward in order to obtain the exhaust. This apparatus is shown in Figure 20.

When the filter reached the laboratory, the sugar was carefully emptied into a beaker of distilled water. After the sugar was dissolved, the dust particles which remained were collected in a weighed Gooch filter containing a felt of asbestos. The filter was then washed with distilled water, dried at a temperature of 100° C., cooled, and again weighed. The increase in weight was taken to be the weight of the dust. From the data so obtained, the weight of dust in milligrams per cubic meter of air was calculated.

Ultimate Number of Dust Particles

The number of ultimate particles of dust was estimated by means of a koniscope, the invention of Professor John Aitken, F.R.S. A portable form of this instrument was imported from Glasgow for the purpose.

The koniscope has not been so much used in sanitary investigations as its merits deserve, and a few words of description may be desirable concerning it. It consists essentially of a brass tube closed at both ends by glass disks. Attached to the tube, near one end, is an air pump with suitable connections and stopcocks (see Fig. 3).

To estimate the number of particles of dust, the instrument was taken to the place where the atmosphere was to be examined. Air was pumped freely through the tube. The stopcock connecting the tube with the outside air was then closed. A rapid stroke of the pump made a partial vacuum in the tube, and this rarification produced a cloud or fog which could be distinctly seen by pointing the tube toward the light and looking through one of the glass disks at the ends. The dust particles served as nuclei about which the moisture condensed.

The depth, color, and intensity of the fog indicated the number of dust particles present. Professor Aitken has invented a more elegant and exact, but less portable, dust counter with which the koniscope can be

FIG. 21. — DUST COLLECTED ON A WHITE TILE EXPOSED AT THE 59TH STREET SUBWAY STATION FOR ONE WEEK

standardized. This more refined apparatus was tried in the subway, but without wholly satisfactory results. It was very delicate in respect to adjustment, and required a better light than was obtainable. The approximate number of particles was usually estimated with the koniscope from the appearance of the fog, and in accordance with the table kindly supplied by Professor Aitken.

Results

The studies of dusts led to the following conclusions:

Physical Character of the Dust.—In appearance, the dust was always black and very finely powdered. It was easily distinguishable by the eye from dusts collected in the streets, and in theaters, churches, office buildings, and mercantile and manufacturing establishments.

The subway dust had a peculiarly adhesive character, which caused it to attach itself securely to all surfaces, even when these were vertically placed and glazed. Dust collected on a white tile exposed at the 59th Street subway station is shown in Figure 21. All parts of the subway which had not been recently cleaned and painted, or were not of a dark color, were sprinkled with this black dust when the investigation began.

The dust had a marked capacity for soiling linen and other articles of clothing. Straw hats and the light-colored garments worn by passengers of both sexes in summer were likely to be soiled by coming in contact with even small accumulations of the dust.

When examined microscopically, the dust was found to be composed of particles of many substances, conspicuous among which were fine, flat plates of iron. In fact, these iron particles could often be seen with the naked eye, glistening upon the hats and garments of persons who had been riding in the subway.

Particles 2 mm. long were, on one occasion, taken from a magnet which had been carried in the hand on a ride of twenty minutes in the cars. By comparison, it was found that magnets hung up in the subway collected more particles of iron than magnets of the same size and strength hung up in an iron foundry or a dry grinding and polishing establishment. Figure 22 shows a magnetic field formed by subway dust.

The size, as well as the number, of the particles depended upon the place where they were found.

Many were so small that they floated in the air as dust. These generally escaped notice, except where beams of sunlight entered the

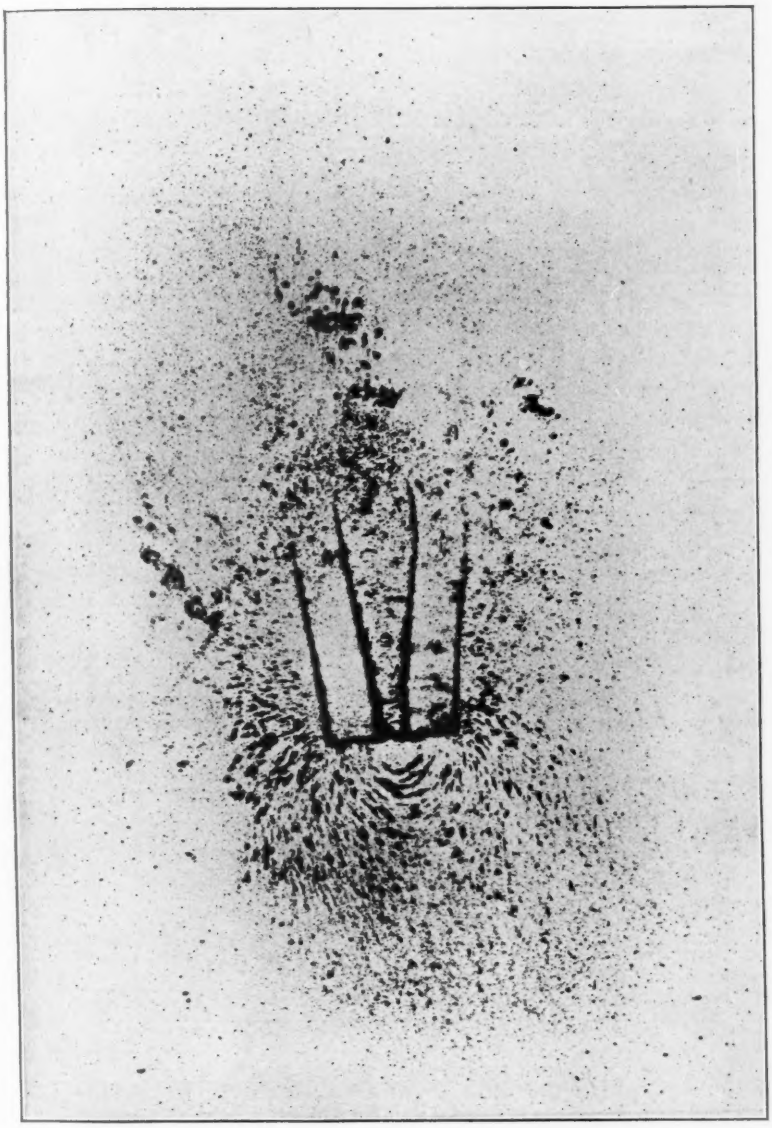

FIG. 22. — MAGNETIC FIELD FORMED BY SUBWAY DUST

subway or where the subway air emerged from some small opening into the sunlight in the streets, under which circumstances they glistened plainly.

Particles of subway dust, not iron, comprised bits of silica, cement, stone, fibers of wood, wool and cotton, molds, and undistinguishable fragments of refuse of many kinds.

Besides the dust which resulted from the grinding of metals, it was evident that the gradual wear and tear of many substances in the subway contributed to the dust.

Chemical Composition of the Dust.—The separate chemical analyses of eleven samples of accumulated dust from the subway showed the following average percentage composition: total iron, 61.30, including 59.89 metallic iron; silica, etc., 15.58; oil, 1.18; organic matter, 21.94, as shown in Figure 23. The results in full are given in Table X.

TABLE X

RESULTS OF CHEMICAL ANALYSES OF ELEVEN SAMPLES OF ACCUMULATED DUST FROM THE SUBWAY

Date, 1905.	Place.	Total iron.	Silica, etc., insoluble in acids.	Oil.	Volatile and organic matter.
		Per cent.	Per cent.	Per cent.	Per cent.
August 3	96th Street station	63.07	12.79	0.88	23.26
August 3	14th Street station	41.77	26.39	1.43	30.41
August 14	Grand Central station	67.35	12.65	1.23	18.77
August 18	23d Street station	54.36	20.50	0.99	24.15
August 17	Brooklyn Bridge station	45.72	21.79	1.97	30.52
August 21	33d Street station	69.66	12.34	0.91	17.09
August 21	Canal Street station	74.78	9.46	0.80	14.96
September 19	116th Street and Lenox Avenue station	66.69	13.84	0.96	18.51
September 19	Times Square station	68.42	7.45	1.00	23.13
September 20	18th Street station	59.84	17.94	1.43	20.79
September 20	28th Street station	62.58	16.28	1.42	19.72
	Average	61.30	15.58	1.18	21.94

Origin of Metallic Dust.—A large part of the metallic iron came from the wear of the brake shoes upon the steel rims of the wheels of the cars.

The wear upon the brake shoes was very severe. By weighing them when they were new and after they were worn out, and determining the number used, it was calculated by the operating company that 1 ton of brake shoes was ground up every month for each mile of subway.

The brake shoes consisted of cast iron with steel inserts.

There was also some loss to the rails and rims of the wheels and to the contact shoes which ran upon the third rail. Probably 25 tons per month would be a low estimate of the weight of iron and steel ground up in the whole subway every month.

Weight of Dust in Subway and Street Air Compared.—The average weight of dust found in the subway by the use of the sugar filters, using all of the results, was 61.6 mg. per thousand cubic feet of air, or 2.25 mg.

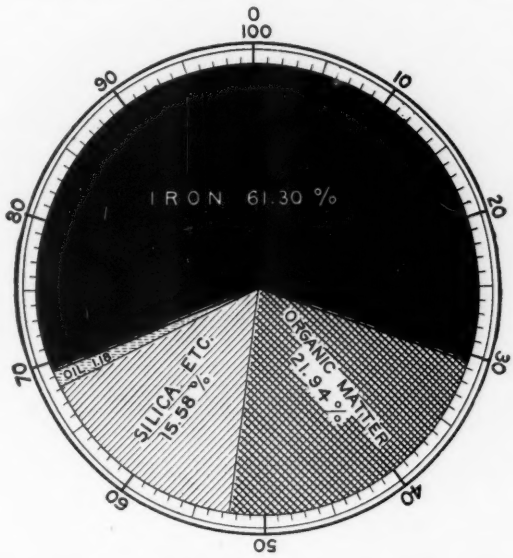

FIG. 23.—COMPOSITION OF SUBWAY DUST AS DETERMINED BY CHEMICAL ANALYSES OF ELEVEN SAMPLES

per cubic meter; in the streets, 52.1 mg. per thousand cubic feet, or 1.83 mg. per cubic meter; difference, 9.5 mg. The maximum amount found in the subway was 204 mg.

Twenty-three comparative tests were made to determine with particular care the weight of dust per thousand cubic feet of air inside of the subway and in the streets at the same time and as near the same place as possible. These showed an excess of dust in the subway of 47 per cent. over that outside. In five cases there was more dust outside, the greatest excess being 30 per cent. In the other eighteen cases the excess of subway dust over street dust ranged from 11 to 800 per cent.

Weight of Dust Inhaled by Passengers.—The weight of dust which the average passenger inhaled in one-half hour in the subway was very slight. Assuming that 360 c.c., or 22 cubic inches, of air were taken in at each breath and that the passenger breathed eighteen times a minute, the total quantity of air which passed into the lungs in half an hour was about 6.88 cubic feet, or 6.50 cubic meters. Using the average of all results, or 61.6 mg. per thousand cubic feet, as the weight of dust suspended in the atmosphere, it appears that the average passenger took into his nose or mouth .42 mg. of dust in a ride of half an hour.

Variations in the Amount of Dust.—The amount of dust found in the air of the subway varied with a number of circumstances.

More dust was found at the arrival ends than at the departure ends of the station platforms. This was probably due to the fact that the brakes were applied near the arrival ends, and to the fact that the currents of air from incoming trains helped to carry dust from those sections of the subway which lay between stations to the platforms.

The stations where the greatest weights of dust were found were express stations; there the amount of metallic dust formed by the braking of the trains was much greater than at the local stations and the travel from the streets greatest.

Bacteria.—The numbers of bacteria found in the dust of the subway were usually smaller than the numbers found in dust which had accumulated outside.

The average result of thirty samples of dust which had accumulated in the subway was 500,000 bacteria per gram of dust. The average obtained from six samples of dust which had accumulated under what appeared to be comparable circumstances in different buildings in New York was 600,000.

The largest number of bacteria found in a sample of subway dust was 2,000,000.

FINAL CONCLUSIONS

A review of the results of the investigation warrants, in my opinion, the following brief statement of the most essential facts determined with respect to the quality of the air.

According to usual sanitary standards, based on chemical and bacteriological analyses, the general air of the subway was always and everywhere satisfactory. The air in the cars in winter is not included in this statement.

According to public opinion, based on the testimony of the senses, the air was everywhere unsatisfactory, especially during the summer months.

My own conclusion was that the general air, although disagreeable, was not actually harmful, except, possibly, for the presence of iron dust. The strong draughts in winter at the stations and the lack of sanitary care exercised over the subway were, however, worthy of careful consideration in this connection.

The high temperature of the subway was its most noticeably objectionable feature. Had it not been for the heat, it is probable that the other unpleasant features would have failed to arouse serious protest. The heat, as is well known, was due to the conversion of electric power into friction. The amount of heat given off by the passengers was so small by comparison as to have had practically nothing to do with elevating the general temperature.

The heat was most objectionable in the mornings and evenings of summer during the hours of greatest travel and when the air outside was cooler than during the rest of the day.

The heat did not indicate that the air was vitiated or stagnant, as was popularly supposed. The subway was hot because a great deal of heat was produced in it, and stored by the materials of which the subway was built. That the heat did not escape rapidly enough for comfort was no proof that the air was not renewed often enough for health.

The carbon dioxide and oxygen analyses indicated that the products of respiration were rapidly carried away. Among the 2,200 carbon dioxide determinations, most of which were made in the subway, no sample of air was found which contained above 8.89 parts of CO_2 per ten thousand volumes, and this amount was found under circumstances which must be regarded as exceptional.

The average excess of carbon dioxide in the subway over that in the streets, 1.14 parts per ten thousand volumes, showed that the air was renewed with remarkable frequency. In the absence of a census giving the number of passengers in different parts of the subway at different hours, it was impossible to calculate just how frequently the air was renewed; but from such estimates as it was possible to make it seemed not improbable that the air of the whole subway was completely renewed at least every half hour.

It is true that the renewal occurred somewhat more frequently in some parts of the subway than in others, but the exchange was always

and everywhere abundant. We must except, of course, from this statement, the cars when closed, and other places where dense crowding occurred.

The controlling condition which regulated the extent to which the air was renewed was the freedom with which it could move in and out of the subway. The air was best where the subway was most open to the streets, and, conversely, it was least satisfactory where the subway was most enclosed. More blowholes would have greatly improved the conditions.

The movement of the trains set in motion the essential ventilating currents. This they did, first, by forcing subway air out and bringing street air in at openings; and second, by moving the air through the subway between openings.

It was fully demonstrated that there were no pockets or other places where air stagnated. Diffusion was everywhere rapid, complete, and satisfactory. I except the cars in these statements, as already indicated.

The fact that there were only about half as many bacteria found in the air of the subway as in the air of the streets under which the subway ran gave ground for the opinion that the bacteriological condition of the subway air was satisfactory, although too much reliance should not be placed upon this guide to its condition. Judgment on this point would have been more conclusive had it been possible to demonstrate that no more harmful bacteria existed in the subway than in the air outside. This was beyond the practicable possibilities of bacteriological technique.

The odors of the subway, like the heat and dust, were objectionable, apparently, chiefly because they were disagreeable. They resulted largely from the operation of the trains. They were, in my opinion, to a large extent preventable.

The sanitary significance of the characteristic black dust of the subway, containing, as it did, over 61 per cent. of metallic particles, remained to be considered at the close of the investigation. At the request of the Board of Rapid Transit Commissioners, this matter is now being studied by me.

NOTES ON THE CHARACTERISTIC CURVES OF THE DIRECT-CURRENT MACHINE

By HARRISON W. SMITH

THE following notes have been found useful in discussing the action of the direct-current machine. There is very little in the treatment that is in any way new, but the subject is here considered in more nearly complete form than is readily available elsewhere in English.

The Magnetization Curve.— When the armature current in a direct-current machine is zero the E. M. F. at the brushes is equal to that induced in the armature, and is given by

$$E_a = \phi N \frac{p}{a} \frac{S}{60} 10^{-8},$$

where ϕ is the flux per pole; N, the number of inductors; S, the speed in revolutions per minute; p, the number of poles; and a, the number of circuits in parallel in the armature.

Since in the given machine N, p, and a are constant, it follows that

$$E_a = kS\phi$$

where k is a constant.

The flux per pole is determined by the ampere turns nI, produced by the field magnet coils, and as n is constant for a given machine, it follows that

$$E_a = k'Sf(I).$$

The magnetization curve shows the relation between E_a and I. It is experimentally obtained by driving the machine at constant speed, and noting the terminal E. M. F. for different values of the field current I. The machine is, of course, separately excited, with no current flowing in the armature except the small current taken by the voltmeter.

Figure 1 shows such a curve for a 3-horse power machine at a speed of 1,100 revolutions per minute. Starting with the field current zero, the induced E. M. F. is approximately 10 volts, due to residual magnetism. As the current is increased to 0.15 ampere the E. M. F. rises, as

shown in curve I, in direct proportion to the field current, since up to this point the permeability of the iron is high and the ampere turns are required almost entirely to overcome the constant reluctance of the air gap. This portion of curve I is, in fact, very nearly a plot of the magnetization curve of the air gap. As the field current is

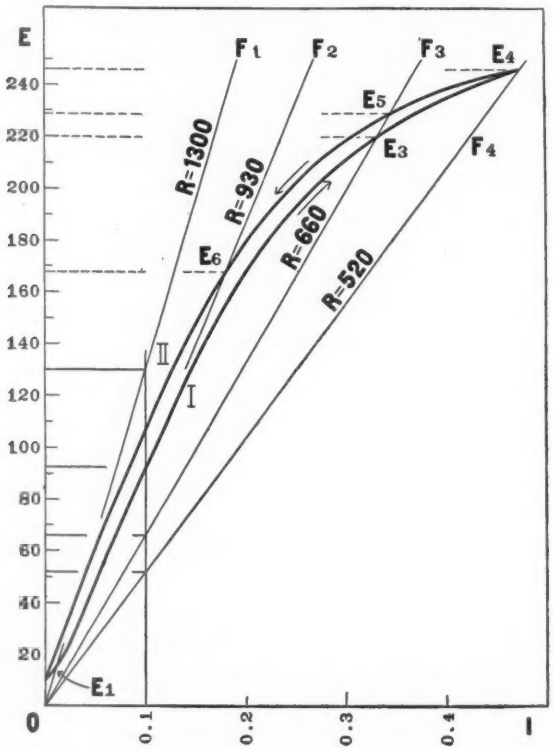

FIG. 1

still further increased, the E. M. F. rises less rapidly, for the iron is now approaching saturation and its permeability is decreasing. Continuing to increase the field current, the E. M. F. finally reaches the value E_4. If, now, the field current is gradually decreased, a different magnetization curve II will be obtained lying somewhat above I, owing to the effect of hysteresis. When the current is again zero the E. M. F. is 10 and the curve joins curve I, thus completing a portion of the hyste-

resis cycle for the magnetic circuit of the machine. The shorter the air gap of the machine, the steeper will be the curve for small values of field current and the further apart will the two curves lie.

This curve corresponds to a speed of 1,100 revolutions per minute; if it is desired to obtain the magnetization curve at any other speed, S, it is sufficient to multiply the ordinates of the given curve by the factor

$$\frac{S}{1100},$$

since for a definite field current the value of E_a is directly proportional to speed.

The Shunt Generator. — Let the machine be connected as a self-exciting shunt generator with a rheostat in series with the field for the purpose of varying the resistance of the field circuit. For any definite field resistance, we may plot the equation,

$$I_f = \frac{E}{R_f};$$

where I_f is the current in the shunt field circuit, R_f is the resistance of that circuit. The plot of this equation is a straight line through the origin. It is called the *field resistance line*, and four plots are shown for the values of field resistance 1,300, 930, 660, and 520. In general, any line through the origin represents some particular field resistance, of which the value can readily be found by noting the value of E at the point where the field resistance line intersects the vertical line through the point $I = 0.1$. For example, OF_1 shows that the field current must be 0.1 when terminal E. M. F. is 130; so that OF_1 corresponds to a resistance in the field circuit of 1,300 ohms.

The point of intersection of the field resistance line, with the magnetization curve, shows the only value of field current which corresponds to the same value of E. M. F. induced in the armature and impressed on the terminals of the field circuit. This point of intersection shows then the E. M. F. which the machine will generate if it is assumed that the induced E. M. F. is equal to the E. M. F. at the brushes; that is, if the machine is not loaded and the small IR drop in the armature due to the field current is neglected.

When the machine is running with the field circuit open the E. M. F. generated is 10 volts. If the field circuit is now closed and its resistance is 1,300 ohms, the E. M. F., E_1, will be given by the inter-

section of OF_1 with the ascending magnetization curve I. When the resistance of the field circuit is decreased to 930, it is apparent that OF_2 will practically coincide with curve I between points whose ordinates are, respectively, 30 and 80. This value of the field resistance is called the *critical resistance*, for it is evident that until the resistance is reduced to this point the machine will generate very little more than 10 volts. When, however, the resistance is made even slightly less than 930, the machine "builds up" rapidly. With $R_f = 660$ the machine generates E_3, and with $R_f = 520$ the terminal E. M. F. becomes E_4. If, now, the field resistance is gradually increased, the terminal E. M. F. will be found by the intersection of the field resistance lines with the curve II. It is evident that the E. M. F. which the machine will generate for a field resistance of 660 may be any value between E_3 and E_5, depending on whether the previous value of the field resistance was greater or less than 660.

In the future discussion only one of the magnetization curves will be considered, but it must be remembered that any deductions which are made from that curve will apply only to the operation of the machine, with increasing or with decreasing flux, according to which of the two magnetization curves is used.

External Characteristic of Shunt Generator. — Figure 2 shows the descending portion of a magnetization curve. The field resistance, corresponding to OF in this case, is given by the point B on the line OF, from which it appears that the resistance is approximately 500 ohms. Consider the conditions under which the field current has the value 0.35, the speed of the machine remaining constant. The magnetization curve M shows that the induced E. M. F. must be E_2, while the line OF shows that 0.35 ampere is maintained in the field circuit by an E. M. F. equal only to E_3. If the machine has no load, this is an

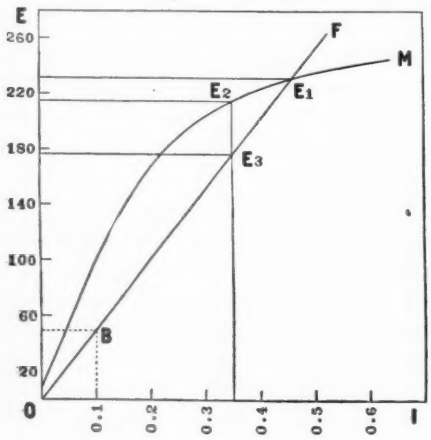

FIG. 2

impossible condition of operation, since the E. M. F., E_2, will produce a field current greater than 0.35, which, in turn, will produce an induced E. M. F. greater than E_2; the machine will build up to E_1.

When, however, a current flows in the armature of a machine the induced E. M. F. differs from the terminal E. M. F. by the IR drop in the armature. In the case of a dynamo,

$$E_a = E_t + I_a R_a,$$

where E_a is the induced E. M. F., E_t the terminal E. M. F., I_a the armature current, and R_a the total resistance of armature circuit from brush to brush.

From Figure 2 this equation is

$$E_2 = E_3 + I_a R_a,$$

from which

$$I_a = \frac{E_2 - E_3}{R_a}.$$

In this case $E_2 - E_3 =$ approximately 38 volts, while $R_a = 1$ ohm; so that the machine may be operating with field current $= 0.35$, provided the load is such that $I_a = 38$ amperes. In this way the external load characteristic of the machine may be plotted; for E_3 is the terminal E. M. F., while $I_a - 0.35$ is the current in the external circuit. By taking other values of the field current, any number of points on the characteristic may be obtained. It is obvious that the effect of armature reaction has been entirely neglected.

Relation of Motor and Dynamo Action. — As indicated above, the point of intersection of the magnetization curve and the field resistance line shows the terminal E. M. F. which the machine generates when no current flows in the armature. In Figure 2, then, the no-load terminal E. M. F. will be slightly less than E_1, since the terminal E. M. F. must be less than the induced E. M. F. by the amount of the $I_a R_a$ drop — in this case about 0.46 volt, since the field current is 0.46 ampere, approximately, and the armature resistance is 1 ohm. Figure 3 is a plot of the region near the point of intersection of the two curves, the scale being fifty times as great as that in Figure 2. It is assumed that the armature revolves at a constant speed and that the armature may either receive or deliver mechanical energy. It is also assumed that the terminals of the machine are connected to mains capable of variation in voltage and capable either of receiving or delivering electrical energy.

When the terminal E. M. F. is E_o the induced E. M. F. has the

same value, and no current flows in the armature; in this case the armature is receiving mechanical energy sufficient to overcome its friction and core losses, while the field current, equal approximately to 0.4625, is flowing in from an external source. Although the armature and field are connected as in any shunt machine, no current flows between them.

The terminal E. M. F., E_2, is chosen, so that $E_1 - E_2 =$ the IR drop in the armature due to the field current necessary to produce E_1. In this case the armature is generating the current necessary for the field, and no current is flowing between the machine and the external circuit.

When the terminal E. M. F. is E_6 the induced E. M. F. is E_5 and the IR drop is $E_5 - E_6 = 1.7$ volts; that is, $I_a = 1.7$ amperes. And since the field current necessary to produce E_5 is 0.458, the machine must be delivering to the external circuit a current $1.7 - 0.458 = 1.242$ amperes. For this field current the machine is, therefore, acting as dynamo, and is delivering a small amount of energy to the external circuit.

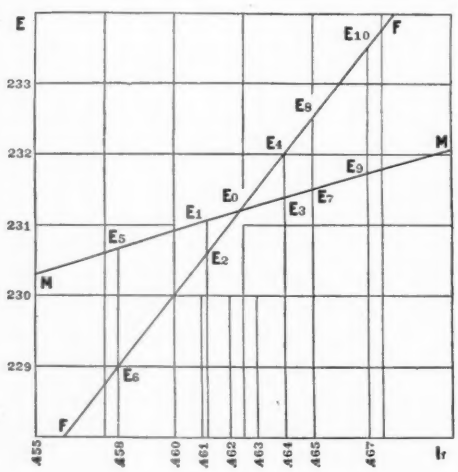

FIG. 3

When the terminal E. M. F. is E_{10}, corresponding on the field resistance line to

$$I_f = 0.467,$$

the induced E. M. F., as shown by the magnetization curve M, is E_9. In this case the IR drop in the armature is $E_{10} - E_9 = 1.8$ volts, and the armature current is, therefore, 1.8 amperes. Since the impressed E. M. F., E_{10}, is greater than the induced E. M. F., E_9, the machine must now be acting as motor, and as 1 ampere is the armature current necessary to run this machine as a motor at this speed without load, the additional 0.8 ampere will cause the armature to transmit mechanical energy to

the shaft to which it is connected. The current supplied from the external source is $I_a + I_f = 2.267$.

When the terminal E. M. F is E_8 the IR drop is $E_8 - E_7 = 1$ volt, so that the armature current is then 1 ampere, which is the current necessary to drive the armature as motor without load. The current delivered to the machine is $I_a + I_f = 1.465$, and the armature is neither receiving nor delivering mechanical energy.

When the terminal E. M. F. is E_4 the armature current is 0.6 ampere, which is not sufficient to supply the losses in the armature. This assists in maintaining the speed of the armature, but a small amount of mechanical energy must also be supplied through the shaft to which the armature is attached. In this case the source of electrical energy to which the terminals of the machine are attached furnishes the energy for the field circuit and a part of that necessary to drive the armature, the balance coming from the shaft to which the armature is attached.

The relation of motor and dynamo action may be stated briefly as follows:

When the terminal E. M. F. is below E_o the machine is acting as dynamo; when above E_o it is acting as motor.

When the terminal E. M. F. is below E_2 the machine is delivering electrical energy to the external circuit; when above E_8 the machine is delivering mechanical energy from its armature.

For any terminal E. M. F. between E_2 and E_8 the machine is receiving both electrical and mechanical energy.

Relation of Terminal E. M. F. and Speed. — In Figure 4 M_1 is the magnetization curve and OF the field resistance line for a given machine at a particular speed, $S_1 : E_1$ is the corresponding no-load terminal E. M. F. of the machine, acting as a shunt generator. If, now, the speed decreases to S_2, the new magnetization curve obtained, as already indicated, is M_2, and the terminal E. M. F. at speed S_2 is E_2. Since the field resistance line is not affected by change of speed, it follows that

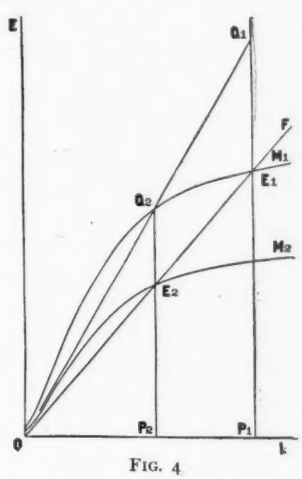

FIG. 4

$$\frac{S_1}{S_2} = \frac{P_2Q_2}{P_2E_2} = \frac{P_1Q_1}{P_1E_1},$$

which gives a method of determining the terminal E. M. F. for any speed, as shown in Figure 5. M is the magnetization curve of a machine at $S = 1{,}100$ revolutions per minute, but the scale of abscissæ

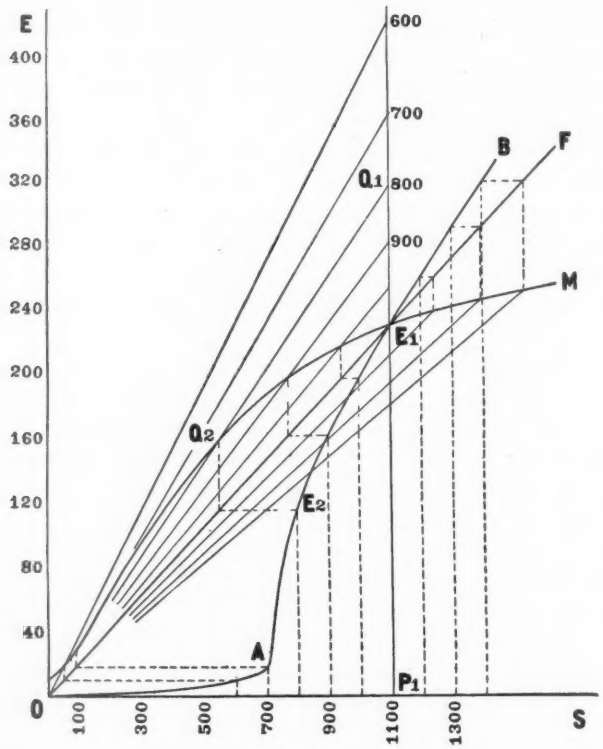

FIG. 5

on which M is plotted is not shown. OF is the field resistance line, and $E_1 = 230$ is the terminal E. M. F. at $S = 1{,}100$. To find the terminal E. M. F. at $S = 800$, for example, draw an ordinate through the point E_1 and locate the point Q_1, so that

$$\frac{P_1Q_1}{P_1E_1} = \frac{1100}{800}.$$

Draw OQ_1, and at the point of intersection, Q_2, of this line with M drop a vertical to the line OF, which gives the terminal E. M. F. for $S = 800$. E_2 is, then, a point on the curve of terminal E. M. F. and speed. This curve is shown in the figure as OAE_2E_1B.

The magnetization curve here shown is for an increasing field current, and the curve of the terminal E. M. F and speed shows, therefore, the rise in E as the machine is started from rest and the speed gradually increased. It will be noticed that E does not rise materially until the speed has attained 700, after which the rise is rapid. This is the *critical speed* of the machine.

Series Turns for Compounding. — The magnetization curve gives a convenient means of determining the number of turns of wire in the series coil necessary to give the same terminal E. M. F. at no load and full load. In Figure 6 M_1 is the magnetization curve for speed S_1, and OF_1 is the field resistance line for $E = 220$ at no load; OP is the shunt field current. Assuming 1 ohm resistance for armature and series coils and full-load armature current, 15 amperes, the induced E. M. F. necessary for full load is

$$E = 220 + 15 = 235.$$

The point B on the magnetization curve corresponding to 235 shows, then, the shunt field current, OQ, necessary to produce this induced E. M. F.; that is, the shunt field current must be increased by the amount PQ or the ampere turns must be increased by PQn, where n is the number of turns in the shunt coils. With the armature current of 15 amperes and the machine-connected *long* shunt, the number of turns in the series coils necessary to give the same terminal E. M. F. at no load and full load is

$$n' = \frac{PQn}{15}.$$

This calculation assumes no armature reaction; if this is to be allowed for, then PQn must be increased by the calculated demagnetizing ampere turns of the armature.

Effect of Change of Speed on a Compound Generator. — In Figure 6 M_2 is the magnetization curve at $S_2 = 1.3\ S_1$, and it is desired to determine the load terminal E. M. F. when the no-load value is 220, the series turns remaining as calculated for the previous case. In order that the no-load terminal E. M. F. may still be 220, the shunt field resistance must be made OF_2, with the corresponding shunt current OP'.

If HJ is then laid off equal to DC, it follows that $OQ'n$ gives the total ampere turns at full load, provided the E. M. F. impressed on the field is still 220. The point K on the curve M_2 shows, then, the induced E. M. F., and the point L, where $KL = BC$, shows the terminal E. M. F. The shunt field current, therefore, instead of being OP' must be that value corresponding to the point G on the field resistance line OF_2, so that the induced E. M. F. will actually be greater than K.

In order to determine the actual terminal E. M. F. of the machine when running at the higher speed with a load of 15 amperes, it is necessary only to find a position for the triangle $B'C'D'$ equal to the

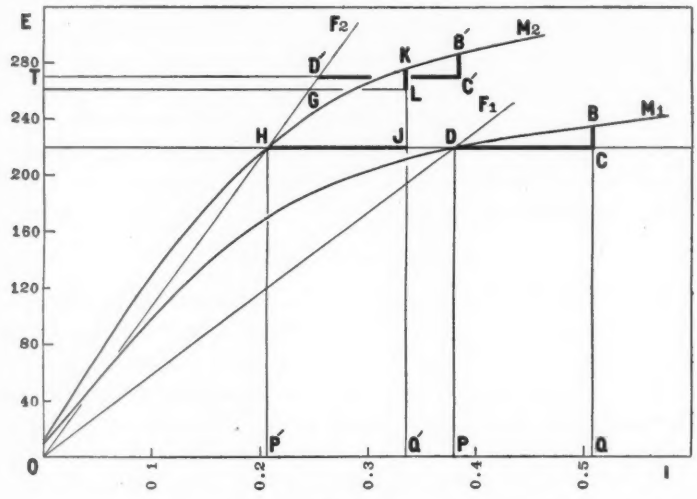

FIG. 6

triangle BCD, such that D' is on the field resistance line OF_2 and B' is on the curve M_2. Then the induced E. M. F., B', is 15 volts above the terminal E. M. F., C', while the total ampere turns $TC'n$ exceed the ampere turns due to the shunt coils $TD'n$ by the amount $D'C'n$, which constitute the ampere turns added by the series coils.

The load terminal E. M. F. is OT, or 270 volts, approximately, and the effect produced by raising the speed of a compound generator is then evidently to increase the relative effect of the series coils. If for a certain speed the characteristic curve of a compound generator is flat, for a higher speed the characteristic will be rising.

Relation of Speed and Field Resistance in Shunt Motor.— Figure 7 shows the magnetization curve M of a shunt machine at speed S_1, with 240 volts impressed on the terminals of the machine; OF_1 is the field resistance line corresponding to this speed, provided the armature IR drop is neglected; and it appears that the field resistance is approximately 580 ohms. Suppose now that it is desired to increase the speed to S_2. The equation of induced E. M. F. is $E_a = kS\phi$.

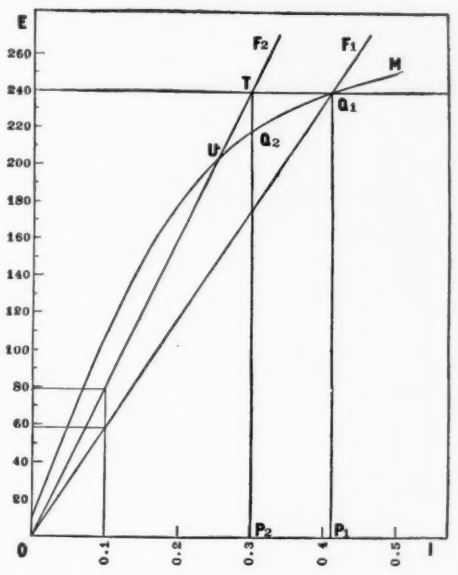

FIG. 7

And in this case, since the impressed E. M. F. is constant at 240 volts, the induced E. M. F., E_a, is constant also, and is assumed equal to 240. The equation becomes, then,

$$S = k' \frac{\mathrm{I}}{\phi},$$

from which

$$\frac{S_2}{S_1} = \frac{\phi_1}{\phi_2};$$

but since the magnetization curve M is obtained by running the machine at constant speed,

$$\phi = k'' E_a,$$

where E_a is any ordinate on the magnetization curve.

We have, then,

$$\frac{S_2}{S_1} = \frac{k'' P_1 Q_1}{k'' P_2 Q_2},$$

or

$$P_2 Q_2 = \frac{S_1}{S_2} P_1 Q_1.$$

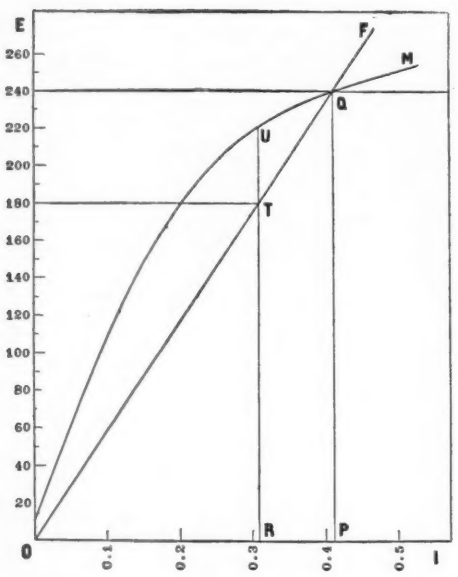

FIG. 8

For any value of S_2, P_2Q_2 is calculated, and the point Q_2 is located on the magnetization curve. OP_2 is then the field current necessary for speed S_2, and this current is maintained by the constant impressed E. M. F. = 240. Therefore the new field resistance line is OF_2 and the corresponding field resistance is approximately 790 ohms. The point of intersection U of the new field resistance line OF_2, with M, shows the E. M. F. which, impressed upon the machine, would drive it at speed S_1, with the field resistance = 790.

Effect of Terminal E. M. F. on Speed of Motor. — In Figure 8 OF is the field resistance line for speed S_1, and OP is, therefore, the field current corresponding. If the terminal E. M. F. is decreased from 240 to 180, the new speed may be found as follows:

Since $$E_a = kS\phi,$$

$$\frac{S_2}{S_1} = \frac{E_2}{E_1}\,\frac{\phi_1}{\phi_2},$$

and we have merely to determine from the curves the values of E_2E_1 $\phi_1\phi_2$ in order to calculate S_2. From the field resistance line $E_1 = PQ$, $E_2 = RT$, and from the magnetization curve $\phi_1 = k''.PQ$, $\phi_2 = k''.RU$. So that

$$S_2 = \frac{RT.k''.PQ}{PQ.k''.RU}\,S_1 = \frac{RT}{RU}\,S_1.$$

It is evident that curve OAE_2E_1B in Figure 5 is a plot of terminal E. M. F. and speed of a motor as well as that of a dynamo.

As regards motor action, this curve represents the rise in speed, as the terminal E. M. F. is gradually increased from zero. It should be remarked, however, that with the low values of terminal E. M. F. the actual performance of the machine departs largely from that indicated by the curve, owing to the relatively large effect of armature reaction when the field is weak.

Speed Curve of Series Motor. — The magnetization curve M of a series machine is shown in Figure 9 for speed = 800. The resistance

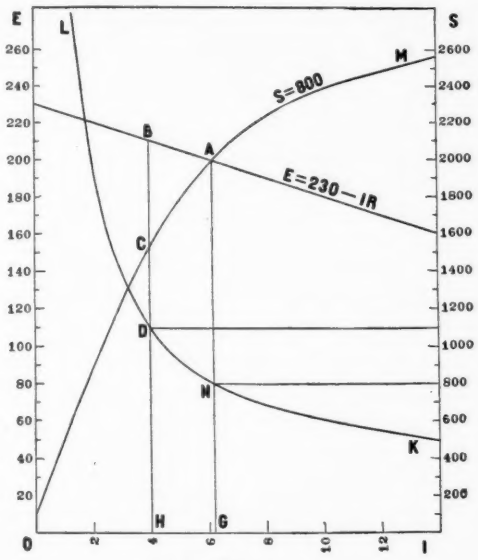

FIG. 9

of this machine, including armature, field, and brushes, is 5 ohms, so that with an impressed E. M. F. = 230 volts the induced E. M. F. must be $E_a = 230 - IR$, where I is the current through the machine. This equation is plotted in terms of induced E. M. F. and current. For speed = 800, curve M is also a plot of induced E. M. F. and current, so that the point of intersection A of the two curves shows the value of the current OG, which alone will correspond to a speed of 800; that is, OG is the only current which satisfies this equation:

$$230 - IR = E_a = Cf(I).$$

If, now, a scale of ordinates be chosen for plotting the curve of

speed and current, the point N will be a point on this curve, for $I = OG$ and $S = 800$.

To find the speed for any other current OH, we have, as before, the equation:

$$\frac{S_2}{S_1} = \frac{E_2}{E_1}\frac{\phi_1}{\phi_2},$$

where $E_2 = HB, \quad E_1 = GA;$

$$\phi_1 = k''.GA, \quad \phi_2 = k''.HC;$$

from which $$S_2 = \frac{HB.k''.GA}{GA.k''.HC} = \frac{HB}{HC}S_1.$$

Substituting the numerical values in the equation, it is found that $S_2 = 1{,}100$; and, doing the same for other values of current, the curve $LDNK$ is plotted and shows the characteristically wide variation of speed of the series motor.

BOOK REVIEWS

The Induction Motor[1]

The power and elegance of the graphical method for the solution of alternating current problems are never more convincingly illustrated than in the use of the circle diagram for the determination of the performance of induction motors. The original paper of Heyland's, appearing in the *Elektrotechnische Zeitschrift*, October 11, 1894, did not at first receive the attention which its importance seems to warrant. In recent years, however, the method therein set forth has been generally adopted.

The treatment given in the pamphlet indicated gives a sufficient idea of the plan to be followed to enable it to be applied by student or engineer, and the examples of detailed working out for motors of various capacities are extremely helpful.

A mere suggestion concerning the induction generator and an all too brief discussion of the single-phase induction motor are added.

H. E. Clifford.

Designs for Small Dynamos and Motors[2]

The work includes twenty-two designs of various types of generators and motors of small capacity for direct and alternating current service. They are well worked out and undoubtedly are of value as indicating the lines along which such designs should be carried. But, after all, designing is an art, and is most certainly not to be learned from any book. Such books, as a rule, are useful only in that they illustrate the applications of the fundamental principles of the electric and magnetic circuits.

H. E. Clifford.

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[1] Alexander Heyland: A Graphical Treatment of the Induction Motor. Trans. from edition 2 by G. H. Rowe and R. E. Hellmund. New York: McGraw, 1906, 48 pp.

[2] Cecil P. Poole: Designs for Small Dynamos and Motors. New York: McGraw, 1906, 186 pp.

Stray Currents from Electric Railways[1]

This admirable treatment of the subject of stray currents includes a discussion of the general principles concerning leakage currents and their distribution in any circuit, the measurement of such currents, and the measures which may be taken to prevent them or reduce their effects to a minimum.

The book has a special force when one considers the very small amount of trouble which has been experienced abroad from such currents. An excellent bibliography is added by the translator.

H. E. Clifford.

A Polyglot Technical Dictionary[2]

The dictionary under review is compiled upon a novel plan; instead of the items being arranged alphabetically they are classified and fully illustrated, so that one seeks a definition from the illustrations rather than from the word. But in case one desires to look up a particular word, there is provided an alphabetical index which refers to the definition by page and paragraph. This index is in two parts: English, German, French, Italian, and Spanish in one alphabet, and the Russian in a second alphabet.

The arrangement of the main part of the dictionary is one that would seem to be particularly useful for persons desiring to write in a foreign language. For example, there are fifteen pages devoted to the mechanical transmission of power, and there are given not only words, but phrases used in reference to machinery of this kind. These being arranged together with illustrations, comparison is easy, and one may readily select the word or phrase that would be most appropriate.

In reading, one would use the alphabetical index, which, referring to the illustration, makes long definitions unnecessary.

Although this American edition is published in New York, with English title-page and preface, the book is distinctly of German manu-

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[1] Carl Michalke: Stray Currents from Electric Railways. Trans. by Otis Allen Kenyon. New York: McGraw, 1906, 101 pp.

[2] K. Deinhardt and A. Schlomann: Illustrated Technical Dictionary in Six Languages — English, German, French, Russian, Italian, Spanish. Vol. I, Elements of Machinery and Metal and Woodworking Tools. New York: McGraw, 1906, 403 pp., 12mo. $2.00 net.

facture, and in some cases the English equivalents given are rather literal translations of German expressions than English technical terms. For example, *Ein Zeichnung in Blei auffertigen* we should render, "To draw in pencil," instead of "in lead." "To draw views of a machine part" is not English, but the German *Einen Maschinenteil in Ansicht darstellen* rendered in English words. To mention a few more cases where the terms given do not correspond at any rate to American usage, the hatchet represented on page 191 is a broadax; the familiar rat-tail file appears on page 175 as a "needle file," and the three-cornered file is called a "three-square file"; and on page 201 the ordinary soldering iron is called a "soldering copper" or "copper bolt." These lapses of English make one wonder how far the corresponding expressions in French, Spanish, and Italian correspond actually to the usage in the countries where those languages are spoken.

A Chemical Cram Book[1]

In his preface the author explicitly disclaims any intention of writing a text-book in the ordinary sense, stating that his book is primarily intended as an aid for those rapidly reviewing the subject while preparing for examination.

Educators will probably differ as to whether special study for an examination, considered as an ordeal, is a desirable thing for the student. Nevertheless, so long as examination marks have far-reaching consequences for the candidate, special preparation will be made, and books like the one before us will be in demand. Of this it must be said that it is distinctly good of its kind. After a brief survey of the fundamental theories of the science, the various classes of organic compounds are taken up in detail, the methods of preparation, properties, chemical behavior, and constitution being discussed concisely in numbered paragraphs. The information is reliable and up to date, and in his generalizations the author has succeeded admirably in securing brevity of statement at a minimum sacrifice of accuracy or clearness. The arrangement of the pages is pleasing to the eye, and the type, paper, and binding are all to be commended. F. J. Moore.

[1] Dr. Kurt Dammann: Kurzes Repetitorium der Organischen Chemie für Studierende. Freiburg in Br. Herder, 1906.

PROCEEDINGS OF THE SOCIETY OF ARTS

FORTY-FIFTH YEAR, 1906-1907

BOSTON, October 25, 1906.

THE 625th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, October 25, 1906, at eight o'clock, fifty-five being present. Professor Louis Derr presided.

Mr. Wesley C. Gilman was elected a member of the Society.

Dr. George W. Pierce, of Harvard University, gave an interesting and instructive address on "The Measurement of Electric Wave Lengths in Wireless Telegraphy." By means of a Leyden jar and induction coil Dr. Pierce produced the oscillatory discharge used in wireless telegraphy, and showed how the measurement of wave lengths could be readily determined. He explained the various methods of connecting the sending apparatus, and showed by lantern slides the photographic reproductions which he had made of these oscillatory discharges. After answering numerous questions relative to wireless telegraphy, which were asked by members of the Society, Dr. Pierce was tendered a vote of thanks for his able and instructive address, and the meeting adjourned.

BOSTON, November 8, 1906.

The 626th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, November 8, 1906, at eight o'clock. One hundred and fifty-five persons were present. Mr. James P. Munroe presided.

Mr. William Lyman Underwood gave an exceedingly interesting and instructive talk on "The Work of the River Drivers in the Maine Woods." Mr. Underwood spent two weeks in this locality, and took many photographs showing the progress of the work at every point.

BOSTON, November 22, 1906.

The 627th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, November 22, at eight o'clock. About sixty persons were present. Dr. William T. Sedgwick presided.

The name of Dr. Robert P. Bigelow was presented to the Society for election to the Executive Committee, to fill the vacancy caused by the resignation of Mr. George W. Blodgett, and he was duly elected.

Dr. George A. Soper, of New York, gave an exceedingly interesting and instructive talk on his recent investigations of the air in the New York subway. Although the number attending the meeting was not large, the brief discussion which followed the address showed the interest taken in the subject. Dr. Soper's paper, containing much interesting data, will be published in full in the March number of the TECHNOLOGY QUARTERLY. The thanks of the Society were extended to the speaker, and the meeting adjourned.

BOSTON, December 13, 1906.

The 628th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, December 13, at 8.25 o'clock. About sixty persons were present. Professor C. H. Peabody presided.

Mr. Alexander E. Brown, Vice-President and General Manager of the Brown Hoisting and Conveying Machinery Company, of Cleveland, Ohio, spoke on the application of hoisting machinery to shipbuilding purposes.

Mr. Brown's wide experience in the design and construction of hoisting machinery made his address one of importance and interest, especially to those who are connected with work along construction lines.

Mr. Brown's remarks were confined to the cantalever type of crane, for the design of which his company is responsible; but as he was one of the pioneers in this line of work, the history of the cantalever crane is the history of the introduction of crane service to modern shipbuilding.

Owing to the lateness of the hour, caused by the delay of trains on which the speaker arrived, no discussion followed the address. After the thanks of the Society were tendered to the speaker, the meeting adjourned.

BOSTON, December 27, 1906.

The 629th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, December 27, at eight o'clock. About seventy persons were present. Professor George F. Swain presided.

Mr. Richard L. Humphrey, of Philadelphia, spoke on the results of the recent San Francisco earthquake. Mr. Humphrey has spent much time in San Francisco studying the effects of the earthquake from an engineer's point of view, and presented a most interesting address, illustrated with lantern slides.

BOSTON, January 10, 1907.

The 630th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, January 10, at eight o'clock. Fifty-three persons were present. Professor Dwight Porter presided.

Colonel E. H. Hewins, Chairman of the Executive Committee, spoke on the urgent need of passing the bill at present before Congress for the establishment of the Appalachian and White Mountain Forest Reserves. Colonel Hewins moved that the SOCIETY OF ARTS authorize the Executive Committee to prepare a set of resolutions to be presented at the meeting of the Society to be held January 24. The motion was seconded, and passed without discussion.

Mr. Henry E. Warren, Superintendent of the Lombard Governor Company, Ashland, Massachusetts, delivered a most interesting and instructive address on "The Governing of High Pressure Water Wheels." He covered the subject in a general way, and brought out many points interesting alike to the layman and the hydraulic engineer. At the close of the address he presented a number of lantern slides showing various installations of water power, the head of which varied from a few hundred feet to several hundred feet. The address was followed by a short discussion, and the meeting adjourned, after extending the thanks of the Society to the speaker.

BOSTON, January 24, 1907.

The 631st regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, January 24, at eight o'clock, forty-three persons being present. Professor H. E. Clifford presided.

Colonel Edmund H. Hewins, on behalf of the Executive Committee, presented a set of resolutions urging upon Congress the passage of the Forest Reserve Bill. These resolutions had previously been printed and a copy sent to each member of the Society. After the reading of these resolutions, a motion was made that they be adopted and a copy sent to each member of Congress from Massachusetts, and the motion was passed without discussion.

Dr. Walter E. Winship, Engineer with the Gould Storage Battery Company, spoke on "Storage Battery Regulations." After the address Dr. Winship illustrated with lantern slides some storage battery installations. The thanks of the Society were expressed to the speaker, and the meeting adjourned.

BOSTON, February 14, 1907.

The 632d regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, in Room 22, Walker Building, on Thursday evening, February 14, at eight o'clock, thirty-three persons being present. Professor C. H. Peabody presided.

Mr. F. L. DuBosque, Assistant Engineer in the Marine Department of the Pennsylvania Railroad, spoke on "The Marine Interests of a Railroad." Mr. DuBosque referred to the peculiar problems of construction and transportation, but laid especial stress on the more interesting point of the transportation of cars and freight by means of car floats and barges, and he spoke briefly of the facilities for placing freight on wharves and on board ship. After the address many questions were asked the speaker, and several exceedingly interesting points were brought out.

The thanks of the Society were extended to the speaker, and the meeting adjourned.

WALTER S. LELAND, *Secretary.*